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MAINTENANCE MANUAL OF ELECTRONIC CONTROL

Maintenance Manual of Electronic Control

Edited by ROBERT E. MILLER
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MAINTENANCE MANUAL OF ELECTRONIC CONTROL

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To My Sons
Bob, Tom, and Jack

PREFACE

This work first appeared as a series of articles in *Electrical Construction and Maintenance*, a magazine designed to keep the practical electrical engineer and technician abreast of new developments and methods in the field.

It is not a reference book for the design engineer; rather, it is a practical installation, maintenance, and service manual for the electrical and electronic technician. The editor, having been an industrial plant construction and maintenance electrician for a number of years, then becoming a graduate electrical engineer, felt that the greatly increasing application of industrial electronic control created a real need for a practical handbook for the working technician. Interviews with hundreds of electrical contractors and industrial electrical engineers and technicians confirmed this fact.

Because of the breadth of the industrial electronic field at the time of the inception of the idea, it was felt that top engineers who were specialists in each type of equipment could best and most authoritatively handle each individual treatment.

The work was planned and executed to involve no mathematics and requires only a knowledge of those fundamentals of electricity which are well understood by the great majority of electrical technicians.

The first chapter on Circuits takes the reader from the very simplest electrical circuit through to the more complicated circuits of electronic motor control and welding control with clear, concise, well-illustrated explanations. From this the reader will gain all the fundamental knowledge of electronic circuit operation necessary to easily understand the following chapters on the use and adaptation of tools and instruments for electronic equipment trouble shooting and also the installation, maintenance, and servicing of specific types of equipment.

It is hoped that the manual will be found extremely useful to electrical technicians who have had no previous experience with industrial electronic equipment as well as to those electronic specialists who wish to acquire a broader knowledge of the installation and care of certain specific types of electronic control.

I wish to express my thanks to my associates, especially W. T Stuart, Editor, and Alice McMullen, Associate Editor, of *Electrical*

Construction and Maintenance, for their valuable advice and assistance. I am especially indebted to all the General Electric Company engineers who not only contributed directly and indirectly to the various chapters, but also assisted materially in formulating the over-all plan. And to Harold J. Mallia, also of the General Electric Company, I wish to express my gratitude for his patient and helpful assistance.

ROBERT E. MILLER

EASTON, PA.
January, 1949

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CHAPTER 1

CIRCUITS OF ELECTRONIC CONTROLS[1]

BY G. M CHUTE

Application Engineer, General Electric Company, Detroit, Mich.

Before anyone can properly maintain an industrial control, he must understand its circuit and the purpose of each part. This is especially true with electronic controls, those whose circuits include tubes such as thyratrons, ignitrons, or the high-vacuum types. To explain some of these electronic-control circuits, this chapter will

1. Show several simple tube circuits operating from d-c supply.
2. Show these same circuits adapted for a-c operation.
3. Explain in detail a commercial form of time-delay relay (a-c, tube operated).
4. Describe an all-tube time-delay circuit.
5. Show the circuit of an ignitron contactor.
6. Explain a commercial form of photoelectric relay.
7. Show how thyratrons, with phase-shifted grid circuits, are used to control a d-c motor operated from an a-c supply.
8. Add a group of sensitive amplifiers to control the thyratrons.
9. Show how thyratrons, used to fire the ignitron contactor may provide variable heat control for a weld.

1. Introducing an Electronic Circuit

To demonstrate a very simple need for an electron tube, Fig. 1-1 first uses a contact S to close the circuit to a small relay whose coil is then energized by battery B. Here S happens to be a tiny contact on the pointer of a voltmeter (which

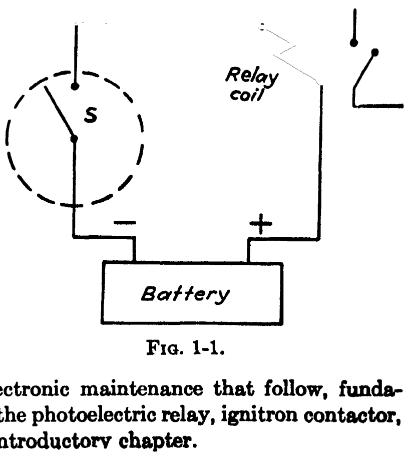

FIG. 1-1.

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[1] As background for the chapters on electronic maintenance that follow, fundamental circuit operations of such devices as the photoelectric relay, ignitron contactor, and time-delay relay are explained in this introductory chapter.

is moved by changes of voltage in some external circuit not shown.) It may close or open the circuit many times, but S soon becomes pitted or damaged by the current, even though that current is only 1/100 amp. To improve this condition, Fig. 1-2 adds a tube T, between contact S and the relay coil. When S is closed, tube T passes the current (1/100 amp or 10 ma) which energizes or "picks up" the relay; however, only about 1/100,000 amp is now flowing through contact S—such a small current that it does not pit or damage the contact. When S is open, tube T passes no current; so the relay is deenergized or "drops out." To use tube T in this way, let us see what circuit changes are required.

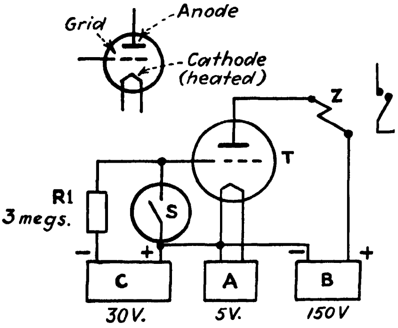

FIG. 1-2.

Basic Circuit Requirements

In Fig. 1-2, we use battery A to heat the filament of tube T, and we use battery C so that its negative terminal is connected (through $R1$) to the grid of T. When S is open, the voltage of battery C serves to keep the grid so much more negative than the cathode (−30 volts) that tube T is unable to pass current. (Figure 1-3 shows that this kind of tube passes no anode current when its grid is more negative than −20 volts.) However, when S is closed, the C-battery voltage appears only across $R1$; the grid is at the same potential as the cathode (or we say that the grid voltage is zero), so tube T passes current.

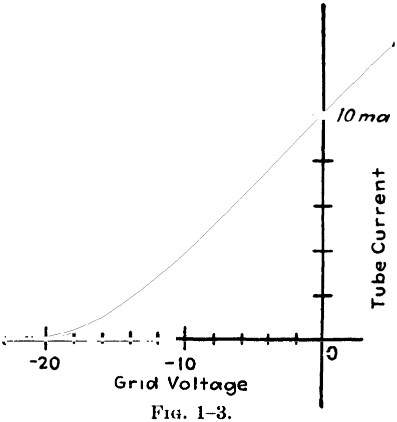

FIG. 1-3.

In a quick review, let us see what makes this electron tube operate. (1) Current passes through tube T, through the space between anode and cathode, requiring no metal-to-metal contact. (2) This current can pass in one direction only, from anode to cathode.[1] (If we reverse battery B, no current will ever flow through tube T.) (3) Heat is required at the filament, before this kind of tube can work. (4) As the grid is made more negative than the cathode, the current through the tube decreases; the tube current stops entirely if the grid is made sufficiently negative.

---

[1] We hesitate to revive the question whether current flows from anode to cathode, or flows from cathode to anode. However, there seems to be much confusion on

If we wish gradually to increase the current passing through tube *T*, we use a variable resistance *R*2 or rheostat in place of contact *S*, leaving the rest of the circuit unchanged, as shown in Fig. 1-4. With *R*2 turned counterclockwise so that all its resistance is in circuit, most of the *C*-battery voltage appears across *R*2, so the potential of grid *G* is about −20 volts (20 volts more negative than cathode *K*), and tube *T* passes no current. If we now turn *R*2 clockwise slowly, the potential at grid *G* gradually becomes less negative, or rises closer to the potential of cathode *K*. This permits more current to flow (anode to cathode) through tube *T*, until this current becomes great enough to pick up the relay.

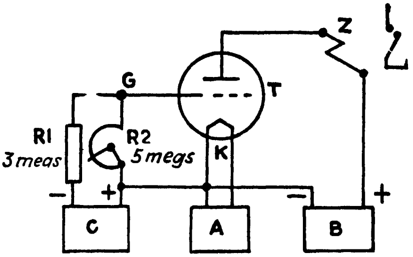

FIG. 1-4.

A Light-sensitive Relay

To obtain a photoelectric ("electric eye") relay, we merely substitute a phototube *P* in place of *R*2, as shown in Fig. 1-5. This phototube

---

this point and some explanation is appropriate here.

Existing American Standard definitions of electrical terms, as now followed by the electrical industry, indicate that positive current flows toward a point of lower or more negative potential, as from anode to cathode. Perhaps these standards should be reworded to agree with evidence presented by the field of electronics.

We may agree that *electrons* flow from the cathode to the anode or to the grid. Whether the current flows in this same direction or in the opposite direction is merely a mental picture or a definition. When explaining an electronic circuit, we can present a more accurate picture by letting the current flow in the same direction as the electron flow.

However, before we teach or state that current flows from cathode to anode, and toward a point of more positive potential, we must not only revise the ASA standards; we must substitute "left-hand" into Fleming's "right-hand generator rule of field, current, and motion" and in similar ways reorient many of the basic statements in elementary physics. Some texts have already included these changes, but they carefully speak in terms of electron flow.

While present standards exist, we confuse the issue if we introduce cathode-to-anode *current* to the electrical technician who has been weaned on positive-to-negative flow of current.

We who talk of anode-to-cathode current may be driving on the left-hand side of the road; although we may prefer to drive on the right-hand side, we shall continue to avoid cathode-to-anode *current* until it becomes standard.

is an electronic tube which passes current (from its anode to its half-cylinder-shaped cathode) whenever light shines on its cathode. With no light, the dark phototube passes almost no current and acts like a very high resistance. By gradually increasing the amount of light, the phototube passes more and more current and decreases its amount of resistance. In this way, phototube *P* controls tube *T* (in the same way as *R*2 in Fig. 1-4). More light shining on the phototube causes grid *G* to become less negative, and this causes tube *T* to pass more current. Note that the phototube itself passes such a tiny current (perhaps 5 μa or 0.000005 amp) that it cannot pick up the relay *Z* directly; however, this phototube current can control the grid potential *G* so that tube *T* passes the larger current necessary to pick up relay *Z*.

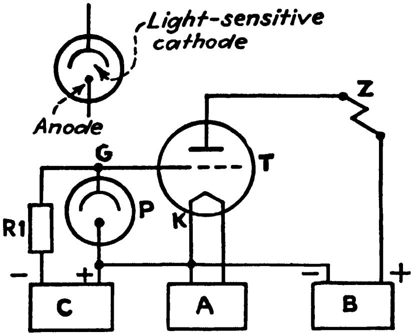

Fig. 1-5.

Returning to Fig. 1-2, if we now wish to cause tube *T* to pick up relay *Z* when we open contact *S*, we merely interchange *R*1 and *S*, as shown in Fig. 1-6. With *S* closed, the voltage of battery *C* appears across *R*1, so the grid *G* is 30 volts more negative than cathode *K*; tube *T* passes no current. At the instant when *S* is opened, the *C* battery is disconnected from *R*1; the voltage across *R*1 instantly disappears and brings grid *G* to the same potential as cathode *K*; tube *T* instantly passes current and picks up relay *Z*.

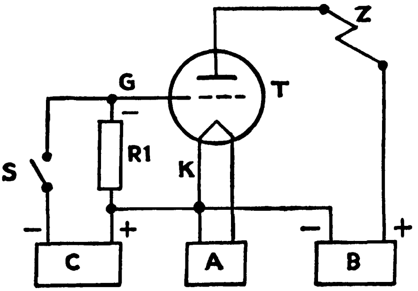

Fig. 1-6.

A Time-delay Relay

Suppose we wish to pick up relay *Z* a short time after *S* is opened, or make the circuit operate as a time-delay relay. This is done merely by adding a capacitor *C*1 across resistor *R*1, as shown in Fig. 1-7. Here, when *S* is closed, the *C*-battery voltage appears across *R*1 as before, and tube *T* passes no current. However, notice that *C*1 is also charged by this same 30 volts of battery *C* and stores some electric energy within itself. At the instant *S* is opened, the *C*-battery voltage is disconnected as before, but the voltage across *R*1 cannot instantly disappear, for capacitor *C*1 still holds some of its energy. For a short time $C1$ acts like a tiny battery and forces current to flow through $R1$, so that there still is a voltage across $R1$ which keeps the grid G negative. After a short time delay, $C1$ will have lost enough of its charge so that the voltage across R becomes small enough to permit tube T to pass current and pick up relay Z. The amount or length of this time delay depends on the amount of resistance (megohms) in $R1$, as well as the amount of capacity (microfarads) in $C1$. By increasing either the megohms or the microfarads, we increase the time delay.

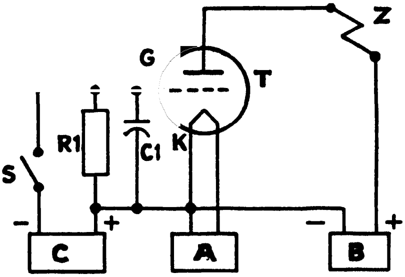

Fig. 1-7.

2. Substitution of Alternating-current Power Supply

Pause a moment to realize that the circuits of Figs. 1-2 to 1-7 are exactly alike except for changes in the grid circuit of tube T. Yet by these changes we obtain first a contact amplifier, then a photo-relay, and finally a time-delay relay. Of course, all these circuits operate from d-c power supplied by batteries. In next showing how to use a-c instead of d-c supply, we shall see that the same method is used for any one of these circuits.

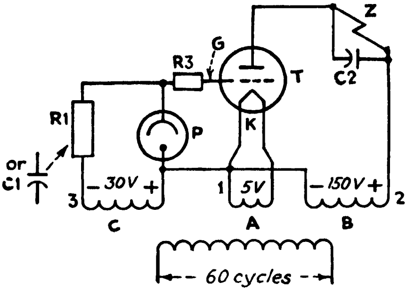

Fig. 1-8

If we substitute a-c supply to the photo-relay of Fig. 1-5, the result in Fig. 1-8 shows that we have used a transformer, whose three secondary windings, A, B, and C, have replaced the three batteries. The 5 volts (rms) of winding A heat the filament just as effectively as the 5-volt A battery. However, although winding B furnishes a complete a-c wave of voltage (so that point 2 is alternately more positive and more negative than point 1, as shown in Fig. 1-9), winding B can force current through relay Z and tube T only during those half-waves when 2 is more positive than 1. (During the other half-waves N, shown in Fig. 1-9, the rectifying action

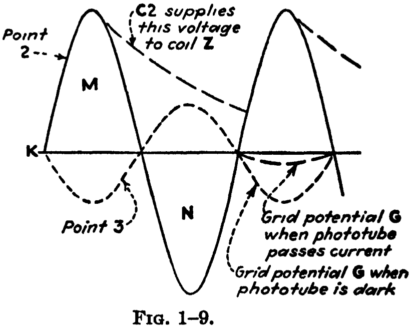
Point 2
C2 supplies this voltage to coil Z
M
K
N
Point 3
Grid potential G when phototube passes current
Grid potential G when phototube is dark

Fig. 1-9.

of tube *T* prevents current flow.) Since relay *Z* is now energized by only half-waves of the a-c supply, it tends to chatter unless some device is added to the circuit to help, such as by adding *C*2 in Fig. 1-8. Capacitor *C*2 charges to the voltage across relay coil *Z* while *T* is passing current; then *C*2 discharges during the next half-cycle, maintaining partial voltage across *Z*, as shown in Fig. 1-9.

Alternating-current Photoelectric Relay

As shown by the above example, whenever a tube is used in an a-c circuit, we must check to see what happens during each half-wave separately. So, in studying the grid circuit of tube *T* (supplied by transformer winding *C* in Fig. 1-8), let us first consider that half-wave when windings *B* and *C* have the polarity shown (which is also the half-cycle marked *M* in Fig. 1-9). If phototube *P* is dark and passes no current, there is no current flowing through *R*1, and grid *G* is at the same potential as point 3. Since point 3 is much more negative than *K* (cathode), tube *T* passes no current, even though its anode is positive during this half-cycle. However, if enough light shines on phototube *P*, it passes current through *R*1, so that most of the voltage of winding *C* now appears across *R*1. The grid *G* (forgetting *R*3) is brought so near to the same potential as cathode *K*, that tube *T* now passes current during this half-cycle *M* and picks up relay *Z*.

Use of Grid Current in Alternating-current Circuits

Is there any current flowing through *R*3 and the grid of tube *T*, in Fig. 1-8? During half-cycle *M* (Fig. 1-9), the grid *G* is always more negative than cathode *K*, so no current passes from grid to cathode or through *R*3. However, during half-cycle *N* the voltage of winding *C* forces a tiny current to flow from point 3, through *R*1, *R*3, and from grid to cathode of tube *T*, to point 1. (*R*3 is a protective resistor; to limit the amount of grid current to a safe value.) No current can pass downward through phototube P, for this tube also acts as a rectifier and refuses to pass current cathode to anode even when illuminated. Notice that grid current can flow (from grid to cathode of tube *T*) during half-cycle *N* but cannot flow during half-cycle *M*, for current never can flow from cathode to grid. Many a-c circuits make use of this feature, which is called "grid rectification." In the photo-relay of Fig. 1-8, a capacitor *C*1 is often used in place of *R*1, and becomes charged by the flow of grid current during half-cycle *N*. Its charge holds the grid *G* very negative during *M;* however, if phototube *P* is illuminated, it passes enough current during *M* to discharge *C*1 and bring the potential of grid *G* close to *K*, letting tube *T* pick up relay *Z*.

3. Alternating-current Time-delay Relay

To convert the time-delay relay of Fig. 1-7 for a-c operation, as shown in Fig. 1-10, the transformer replaces the batteries, and *C*2 is added as before; the connection to *R*1 and *C*1 is moved, and *R*2 is added. With switch *S* closed, during half-cycle *M* the voltage of winding *C* forces current to flow only through *R*2 and switch *S* to point 3; during half-cycle *N* the current flows through *R*2 in the opposite direction. Also, current now flows from 3 through *S*, *R*1, and through tube *T* (grid to cathode) to point 1. Most of the voltage of winding *C* appears across *R*1 and charges *C*1 to this same voltage. During the next half-cycle, when grid rectification prevents current flow through *R*1 in the reverse direction, *C*1 loses a very small part of its charge by forcing current to flow through *R*1 (from 4 toward *G*). So as long as *S* is closed, the voltage across *R*1 alone keeps grid *G* so negative that tube *T* passes no current.

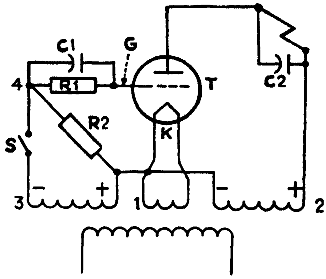

FIG. 1-10.

In Fig. 1-10, when *S* is opened, current through *R*2 stops instantly and point 4 is at the same potential as cathode *K*. Voltage still remains across *R*1 while *C*1 gradually discharges through *R*1. This *R*1 voltage keeps grid *G* more negative than *K*. After the desired time delay (determined by the size of *R*1 and *C*1), the voltage across *R*1 has become so small that grid *G* is near the same potential as cathode *K*, and tube *T* passes enough current to pick up relay *Z*. If *S* is reclosed, relay *Z* drops out instantly. (If *C*2 is large enough, its stored energy may be sufficient to keep relay *Z* energized for many cycles after tube *T* stops passing current.)

If *R*1 and *C*1 of Fig. 1-10 are made small enough, the voltage across *R*1 disappears quickly; the opening of switch *S* causes almost instantaneous pickup of relay *Z*. The circuit of Fig. 1-10 is thus changed from a time-delay relay into a contact amplifier—the a-c equivalent of Fig. 1-6.

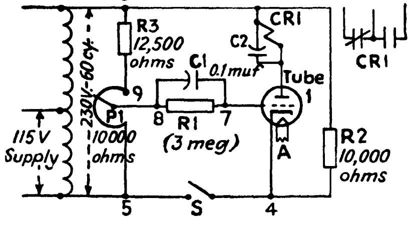

FIG. 1-11.

Figure 1-11 shows the circuit of a time-delay relay manufactured for general-purpose use in industry. It includes a provision (by turning *P*1) for selecting the length of time delay. The circuit starts its time-delay action at the instant switch *S* is closed; at the end of the desired time delay, tube 1 picks up relay *CR*1 whose contacts may be connected to close some other circuit, or to open that circuit if preferred.

In Fig. 1-11, the power supply is 115 volts, 60 cycles, a-c and the autotransformer (at left) increases this to 230 volts for use in the circuit of tube 1. A separate transformer winding *A* supplies the low voltage for heating the filament of tube 1. Notice here that tube 1 has a separate cathode (connected to point 4) which is indirectly heated; there is no electrical connection between the filament and the cathode; the red-hot filament heats the cathode so that the current flows through tube 1 from its anode to the heated cathode.

The current that picks up or energizes relay *CR*1 must flow from point 6, through *CR*1 and tube 1, to point 4, and through switch *S* to point 5. Therefore, the closing of *S* makes it possible for tube 1 to pass current, but not until the grid of tube 1 reaches a potential that permits this current to flow. We shall see that the grid potential of tube 1 prevents the flow of this current until the end of the desired time delay. Reopening *S* drops out *CR*1 and resets the circuit for the next time-delay operation.

Even while *S* is open, the grid circuit of tube 1 is in action. During those half-cycles when point 6 is more positive than point 5, current can flow only through *R*3 and *P*1; no current flows through tube 1. However, during each half-cycle when 5 is more positive than 6 (and *S* is still open), current flows from 5 to the slider of *P*1, through *R*1, from grid to cathode of tube 1, to 4, through *R*2 to 6.

Circuit Performance during a Long Time Delay

First turn *P*1 so its slider touches at point 5; the entire voltage between 5 and 6 (230 volts) now forces current through the *R*1-grid-cathode-*R*2 circuit. Since the 3-megohm resistance of *R*1 is so much greater than any other resistance in this circuit, as much as 200 volts appears across *R*1, and *C*1 becomes charged by this voltage. Here 200 volts is the effective (or rms) value of this a-c voltage wave, but capacitor *C*1 charges to the crest value ($\sqrt{2} \times 200$) or about 280 volts. During the next half-cycle, the grid rectification of tube 1 prevents any reverse flow of current; *C*1 loses only a very small part of its voltage by discharging through *R*1. So, as long as switch *S* remains open, about 280 volts is steadily maintained across *R*1, and the point 7 end of *R*2 is 280 volts more negative than the point 8 end.

At the instant switch *S* closes, connecting cathode 4 to point 5, the charge on *C*1 is holding the tube 1 grid at a potential 280 volts more negative than the cathode. However, *C*1 now continues to discharge through $R1$, so the grid potential becomes less negative, or rises as shown in Fig. 1-12. After about 1 sec delay (which is the longest time delay for which this certain relay may be set), the grid potential

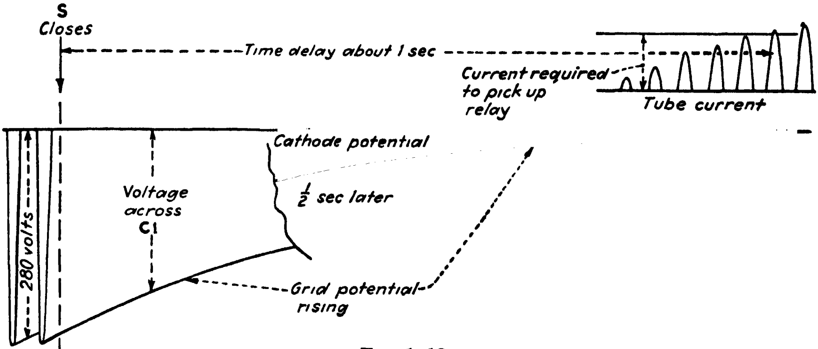

FIG. 1-12.

becomes so close to the cathode potential that tube 1 begins to pass current, which quickly increases to the amount required for the pickup of relay $CR1$.

Now turn $P1$ so that its slider touches at point 9. Only the voltage between 9 and 6 (about 130 volts) now forces current through the $R1$-grid-cathode-$R2$ circuit. About 115 volts is applied across $R1$, and $C1$ charges to the crest value ($\sqrt{2} \times 115$) or about 160 volts, as shown at H in Fig. 1-13. So point 7 is being kept 160 volts more negative than point 8.

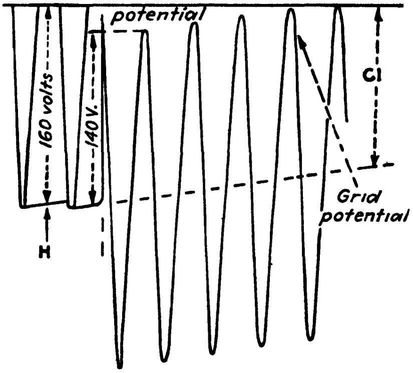

FIG. 1-13.

When switch S closes, the grid of tube 1 is held negative by the charge of $C1$ as before; in addition, the a-c voltage across potentiometer $P1$ also influences the grid potential. As shown in Fig. 1-13, the alternating voltage across $P1$ subtracts from the direct voltage across $C1$, so that the grid potential is raised to within 20 volts of the cathode potential. After a time delay of only four cycles, or 1/15 sec, the decrease of $C1$ voltage has raised the grid potential so close to the cathode that tube 1 passes current and picks up relay $CR1$.

Obviously, if *P*1 is set at a middle position, the resulting time delay will be about halfway between the longest value (Fig. 1-12) and the shortest value (Fig. 1-13). Figure 1-14 illustrates such a condition.

The Thyratron Tube for Greater Current

All the circuits so far described use a high-vacuum tube whose cathode is heated; the current flowing through such a tube is usually only a small fraction of an ampere. When a greater current is needed to pick up a larger contactor instead of relay *Z*, a thyratron tube may be substituted in a circuit which uses a-c supply, such as Fig. 1-8 or 1-11. The thyratron uses a heated cathode and has an anode and grid much like the high-vacuum tube. However, instead of a high vacuum inside its enclosure, the thyratron has a vapor of mercury or a gas. The anode-to-cathode current through such a tube may be as much as a hundred times greater than the current of a similar high-vacuum tube. The symbol for such a vapor-filled tube includes a dot.

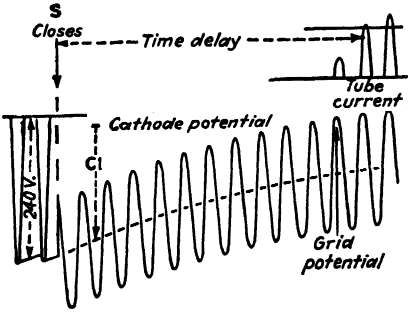

FIG. 1-14.

Such a thyratron is sometimes used in the time-delay circuit of Fig. 1-11, and the coil of *CR*1 is then designed to pick up at a greater current, such as 1/10 amp.

4. Time-delay Circuit of a Spot-welder Control

To obtain a time delay as short as 1 or 2 cycles, frequently needed for spot-welding aluminum and other metals, an all-tube circuit is used, as shown in Fig. 1-15. The purpose of the circuit is to permit thyratron tube 3 to pass current just one half-cycle of the a-c supply and then stop, even though the starting switch remains closed a longer time. (Later it will be seen that *R*9 may be adjusted to permit tube 3 to pass current for a greater number of half-cycles, if desired.)

The a-c supply forces current to flow only through tube 3; the timing circuit operates on direct current. Rather than use a battery or external d-c source, this circuit provides its own d-c supply by means of rectifier tube 1. This rectifier arrangement is frequently found in electronic controls. Briefly, the alternating current induced by voltage *A*, which appears at *T*1*S* (secondary of transformer *T*1), passes through tube 1, the positive half-cycle through the right-hand anode of tube 1, the negative half-cycle through the left-hand anode.

The output from tube 1 cathode, shown as *B*, appears as a pulsating voltage, all the half-waves being of the same polarity. By means of reactor *X* and capacitor *C*1, this voltage is filtered or smoothed into a steady d-c supply, which is positive at the top of the timing circuit and negative at the bottom.

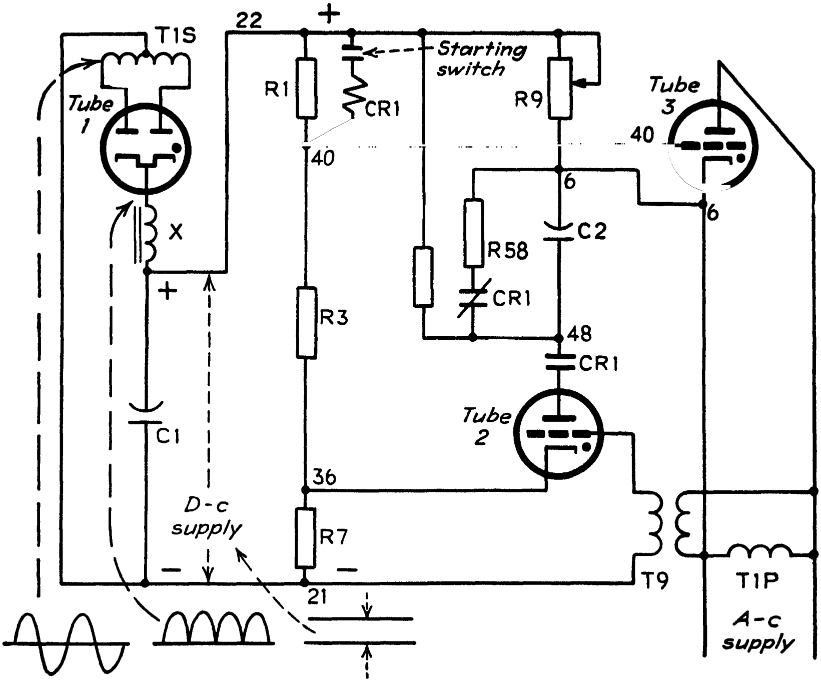

Fig. 1-15.

Starting Switch Open. While the starting switch remains open in Fig. 1-15, let us examine the grid and cathode potentials of tube 3. The grid is connected to point 40, which is at some fixed potential more negative than point 22. (Resistors *R*1, *R*3, and *R*7 act together as a voltage divider, whose most positive potential is at the top. Point 40 is below 22 and therefore is more negative than 22; similarly, point 21 is more negative than point 36.) The cathode of tube 3 is connected to point 6 at the bottom of *R*9. However, since the starting switch has not picked up relay *CR*1, the *CR*1 contact above tube 2 is open, so there is no current flowing through tube 2 or *R*9; there is no voltage drop across *R*9 so point 6 (cathode of tube 3) is at the potential of point 22. Since the tube 3 grid (at point 40) is more negative than the cathode (which is at the potential of point 22), tube 3 cannot pass current. While relay *CR*1 is not yet energized, its normally closed contact is connecting *R*58 across capacitor *C*2; there is no charge on *C*2, so points 6 and 48 are at the same potential.

Starting Switch Closed. When the starting switch closes, picking up relay *CR*1, then *R*58 is disconnected from *C*2, and *C*2 is now connected to the anode of tube 2. No current yet flows through thyratron tube 2, for its own grid is connected to point 21 which is more negative than point 36, the cathode. However, at one certain point in each cycle of the a-c supply, transformer *T*9 produces a voltage peak (shown at *A* in Fig. 1-16) which fires tube 2. Therefore, no matter when *CR*1 picks up, tube 2 passes no current until the next positive peak of *T*9 occurs. When tube 2 fires, tube 3 instantly passes current also, as explained below.

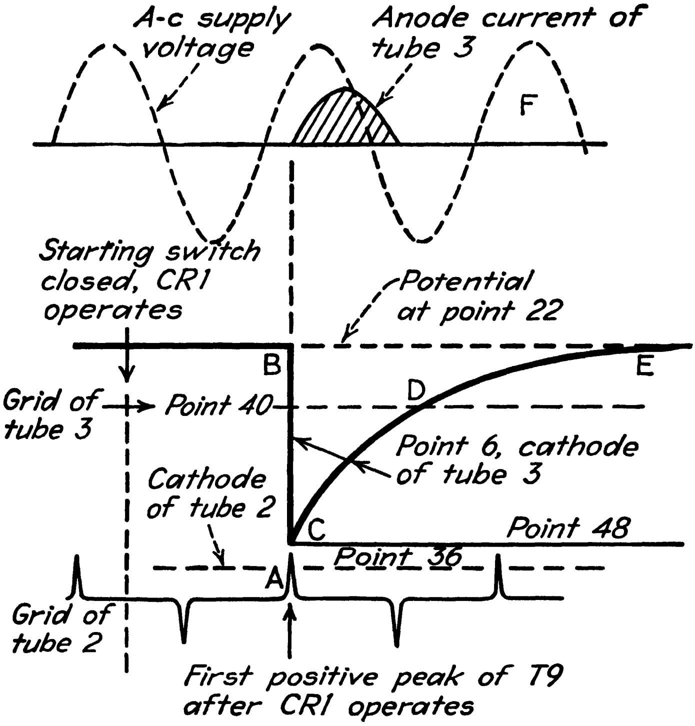

FIG. 1-16.

It should be here mentioned that thyratron tube 2, although fired by such a brief voltage peak from transformer *T*9, continues to pass current as long as *CR*1 remains energized. Any vapor-filled tube acts in this way; its grid can prevent the tube from firing, but the grid has no further effect after the anode current once starts. Only the removal of anode voltage can cause the current to stop.

When tube 2 passes current, this current flows from point 22 through *R*9 into capacitor *C*2, and through tube 2 to point 36 and through *R*7 to point 21. When a vapor-filled tube like tube 2 is passing current, the tube anode is about 15 volts more positive than its cathode (or, we say that the tube voltage drop is 15 volts). Therefore, the potential of point 48 is suddenly lowered (from its previous positive potential at 22, marked *B* in Fig. 1-16) to a value close to point 36, marked *C*. At the same instant, since *C*2 has no charge and points 6 and 48 are at the same potential, point 6 (cathode of tube 3) is also suddenly lowered close to point 36. Since 36 on the voltage divider has a potential considerably below point 40 (grid of tube 3), it is seen that the firing of tube 2 makes the cathode of tube 3 more negative than the tube 3 grid, so tube 3 fires.

Time-delay Action. The time-delay action of Fig. 1-15 starts when tube 2 first passes current. This current flows into capacitor *C*2, at a rate that can be adjusted by resistor *R*9. As voltage now begins to appear across *C*2, the potential of point 48 (bottom of *C*2) remains fixed but the potential of point 6 (top of *C*2 and also the cathode of tube 3) rises as shown by line *CDE* in Fig. 1-16. When this cathode potential rises above the potential of the grid (at *D*), tube 3 cannot pass current during the following half-cycle marked *F*. In this way tube 3 is prevented from passing current during more than 1 half-cycle of the a-c supply; moreover, thanks to the accurately timed voltage peak of transformer *T*9, the current of tube 3 can start to flow at only one certain point in the cycle. These features are quite necessary in the accurate or synchronous control of a spot welder.[1]

In the complete welder-control circuit, of which Fig. 1-15 is only a part, thyratron tube 3 has a companion, tube 4. Together these tubes act as an a-c switch.

Electronic Tubes as an Alternating-current Switch. Figure 1-17 shows two thyratrons connected as an a-c switch; they close or open the load circuit much like a single-pole contactor. Each tube by itself passes current in only one direction, but this connection of

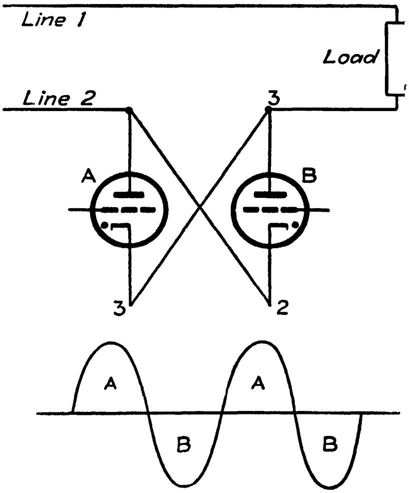

FIG. 1-17.

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[1] Such synchronous control is more completely described in "Electronic Control of Resistance Welding," McGraw-Hill Book Company, Inc., New York, 1943.

Fig. 1-17 permits alternating current to flow through the two tubes combined. This connection is called "inverse parallel," wherein the anode of each tube is connected to the cathode of its companion tube. To illustrate, when line 2 is positive (during half-cycle marked *A*), current passes down (anode to cathode) through tube *A* to point 3 and through the load to line 1. During the next half-cycle marked *B*, line 1 is positive, so current passes from line 1, through the load to point 3, down through tube *B* to line 2. When the grids of these tubes are kept quite negative (by circuits not shown), neither tube passes current, so the load circuit is open. Raising the grid potential permits both tubes to pass current or "fire," and alternating current is applied to the load.

The resistance drop within these vapor-filled tubes cannot limit the amount of current flowing through them; when the grids permit anode current to start, the amount of that current depends on the load. Alternating current loads as great as 25 amp can be switched by the larger sizes of thyratrons.

5. Ignitron Contactor

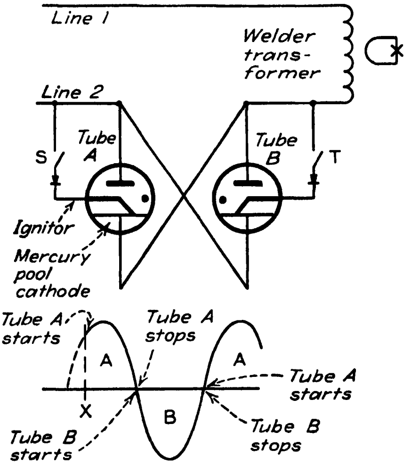

FIG. 1-18.

To switch a-c loads greater than 40 amp, another type of electron tube is used, called the "ignitron." This tube is not heated. As its cathode is a pool of liquid mercury, the enclosure contains mercury vapor. Current flows through this vapor, from the anode to the mercury pool, but only after the flow is started or "ignited" by means of an ignitor, whose tip dips down into the mercury pool, as indicated by the tube symbol in Fig. 1-18. To fire an ignitron or make it pass anode current, the supply voltage must first force current (15 to 40 amp) to flow from the ignitor into the mercury pool. This causes a tiny arc to appear at the ignitor tip, instantly ionizing all the mercury vapor and making it able to carry current from anode to cathode. This large anode current produces so much heat within the tube that most ignitrons are cooled by water flowing within a metal jacket surrounding the tube. Figure 1-18 shows two ignitrons connected as an a-c switch or single-pole contactor, so as to close the circuit to a spot-welder transformer. Neither ignitron passes current while switches *S* and *T* are open. However, if both *S* and *T* are closed at the point marked *X* (in half-cycle *A*, when line 2 is positive), ignitron *A* instantly passes current which flows during the rest of half-cycle *A*. However, ignitron *B* cannot pass current until half-cycle *B* (when line 1 is positive) and after the current of tube *A* stops.

Notice that the circuit through *S* and the ignitor is in parallel with the main anode-to-cathode circuit of tube *A*. When *S* closes, current first flows through *S* and the ignitor causing the arc that ionizes the mercury vapor in tube *A*. This instantly permits load current to flow directly from anode to cathode in tube *A*. The resistance of this main current path from anode to cathode is so much lower than that of the circuit through *S* and the ignitor, that the current flowing in the ignitor becomes negligible. As soon as the current stops flowing in tube *A* and the voltage at the anode of ignitron *B* has become more positive than its cathode, tube *B* is "fired" in the same manner, by current flowing first through switch *T* and the ignitor, which instantly makes the mercury vapor in tube *B* able to carry the load current directly from anode to cathode. We see that, although the load current is carried mainly by the anode-cathode circuit, this flow must be started or "ignited" every half-cycle separately.

Ignitor Circuit. Instead of two ignitor circuits controlled by separate switches, as in Fig. 1-18, the ignitors can be connected together through a single contact *C*, as shown in Fig. 1-19. With *C* closed and line 2 positive, current flows from 2, up through tube *B*, from the mercury pool into the ignitor to 4, through *C* and into ignitor 5, to the mercury pool of tube *A*, to point 3, through the load to line 1. This fires tube *A*, which immediately passes current from anode 2 to cathode 3. Although this ignitor current fires tube *A* in normal fashion, this same current flows in reverse direction in tube *B*, or from pool to ignitor. Such reverse current definitely damages the ignitor and decreases tube life. To prevent this reverse current, copper oxide (metallic) rectifiers are added as shown in Fig. 1-20. Each rectifier is a stack of specially coated copper disks arranged so that they have low resistance to cur-

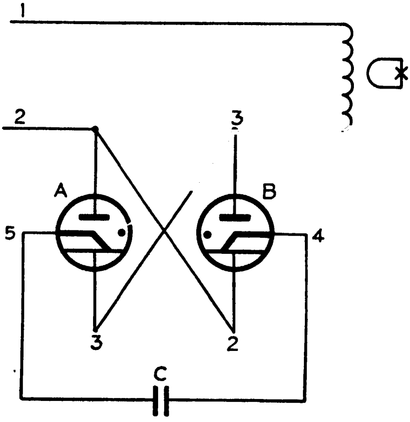

FIG. 1-19.

rent flow in the direction indicated by the symbol arrow, but very high resistance to opposite current flow.

Figure 1-20 shows the circuit used in a commercial ignitron contactor. The ignitrons, connected inverse parallel, close or open only one side of the a-c line. Both ignitrons pass current when the control switch is closed. To fire ignitron tube 1, the current first flows *ABCDEFGHIJ*. This current flowing into ignitor *G* causes tube 1 to pass current, which flows *AHIJ*. During the following half-cycle, ignitor current flows first through path *JIHFEDCKBA*, which fires tube 2 so that load current then flows *JIBA*.

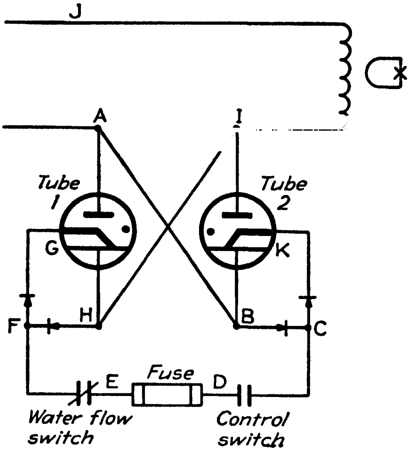

Fig. 1-20.

The control circuit *CDEF* carries each ignitor current in turn. Although this current must reach 25 to 40 amp momentarily to fire the ignitron, it flows such a small portion of each cycle that a 3- or 6-amp fuse serves during normal operation. If an ignitron fails to fire or becomes "hard starting," the ignitor current flows a larger portion of each cycle and blows the fuse. In the same circuit, the flow-switch contact opens when there is insufficient water flowing to cool the ignitrons.

In Fig. 1-20, the current flows steadily through the ignitron (each tube passing current during its own half-cycle) as long as the control switch remains closed. Later we shall see how this control switch may be replaced by a pair of thyratrons, so as to fire the ignitrons with the greater accuracy needed in the synchronous control of welders.

6. General-purpose Photoelectric Relay

Figure 1-21 shows a light-sensitive relay which may be operated from either a-c or d-c power supply. As explained below, when sufficient light shines on phototube 3, this permits current to flow through tube 2 causing relay *CR* to pick up and operate its contacts to control external circuits.

If points 1 and 2 are connected to a 115-volt a-c supply, the portion of Fig. 1-21 within the dotted line serves to convert this alternating current into a d-c voltage which appears between points 8 and 1. That is, tube 1 acts as a half-wave rectifier which permits current to flow through it during only the half-cycles when the tube 1 anode is positive. Since this tube current flows in only one direction, it charges capacitors *C*1 and *C*2, which smooth this pulsating tube output into a usable steady d-c voltage; in this way these capacitors and resistor *R*7 act as a filter. However, if points 1 and 2 are connected to a 115-volt d-c supply (with the positive side at point 2),

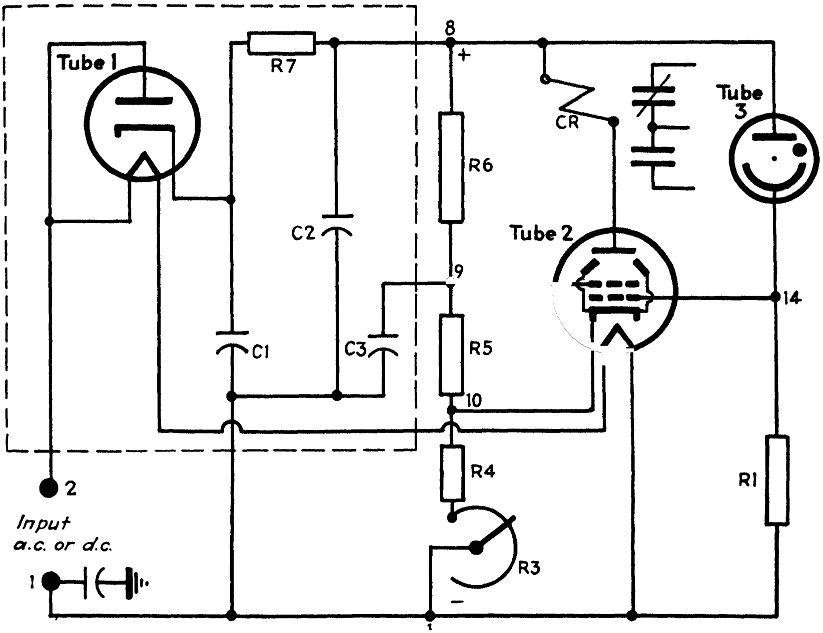

FIG. 1–21.

current flows steadily through tube 1 and *R*7, and a d-c voltage again appears between points 8 and 1.

In circuits supplied only by alternating current, the tube filaments often work at low voltage furnished by a small transformer. Since such a transformer cannot be used in Fig. 1-21 on d-c supply, the tube filaments are designed to operate directly at supply voltage. Tubes 1 and 2 are built in one enclosure, using a single socket.

Between points 8 and 1 in Fig. 1-21, resistors *R*3, *R*4, *R*5, and *R*6 merely divide the d-c voltage into usable parts. The current that picks up *CR* must pass from 8 through the *CR* coil, anode to cathode of tube 2 to point 10, and through *R*4 and *R*3. This tube current cannot flow when the control grid of tube 2 (at point 14) is considerably more negative than the cathode (point 10), as when the light beam at phototube 3 is interrupted. When phototube 3 is dark, it acts as a very high resistance, much greater than *R*1, so that the potential of point 14 is close to that of point 1, and therefore is more negative than point 10.

When the light beam reaches phototube 3, this phototube permits enough current to flow (from 8 through phototube and *R*1 to point 1) to cause a voltage drop across *R*1. This raises the potential of point 14 (grid of tube 2) so as to permit anode current to flow through tube 2 and pick up *CR*. If the *R*3 slider is turned clockwise, the amount of light required to operate the relay is increased. This increases the resistance and voltage drop between points 10 and 1 and raises the cathode of tube 2 to a higher potential. To turn on tube 2 we must now raise its grid (14) to a higher potential also. This requires more current flow through *R*1 and more light on phototube 3.

In describing the operation of tube 2, we have mentioned only one grid, as though tube 2 were a triode. In Fig. 1-21 the symbol of tube 2 shows that it is a beam-power tube—a form of tetrode having deflecting plates connected to its cathode. This more complex tube gives superior performance but is controlled, in the same way as a triode, by means of the potential of one grid close to its cathode. The other grid is connected to point 9 whose potential is not affected by the phototube circuit.

Photoelectric Pyrometer

Very similar to Fig. 1-21 is the circuit of a photoelectric pyrometer shown in Fig. 1-22. Phototube 3 "looks at" a red-hot object and causes tube 2 to permit just enough anode current to flow to make the instrument pointer indicate the temperature of the object.

This pyrometer circuit operates from an a-c power supply. Through transformer *T*1 and tube 1, this alternating current is rectified into pulsating direct current, then smoothed or filtered by capacitors *C*1 and *C*2 and reactor *X*. Since the resulting d-c voltage (shown at *A* in Fig. 1-22) can change if the a-c supply voltage fluctuates, a voltage-regulator tube 4 is added, so that a constant voltage is obtained at *B*, thereby causing more accurate performance of the pyrometer circuit.

Such a voltage-regulator tube contains a gas or vapor. Its cathode is not heated. It is the nature of such a tube to maintain a constant arc drop. Whenever current flows through the tube, the voltage measured between its anode and its cathode remains at one steady value and does not change as the tube current changes with line-voltage fluctuations.

The kind of gas used in tube 4 causes a constant 90 volts to be maintained at *B*. To give this result, tube 4 must operate in series with a resistor (*R*8) which absorbs any variation in voltage *A*. For example, if *R*8 is 5,000 ohms and *A* is 140 volts, the voltage drop across *R*8 is 50 volts and the current flowing through *R*8 is 0.01 amp or 10 ma. If voltage A rises to 160 volts, the voltage drop across *R*8 increases to 70 volts because tube 4 instantly increases its anode current by 4 ma, so that 14 ma flows through *R*8.

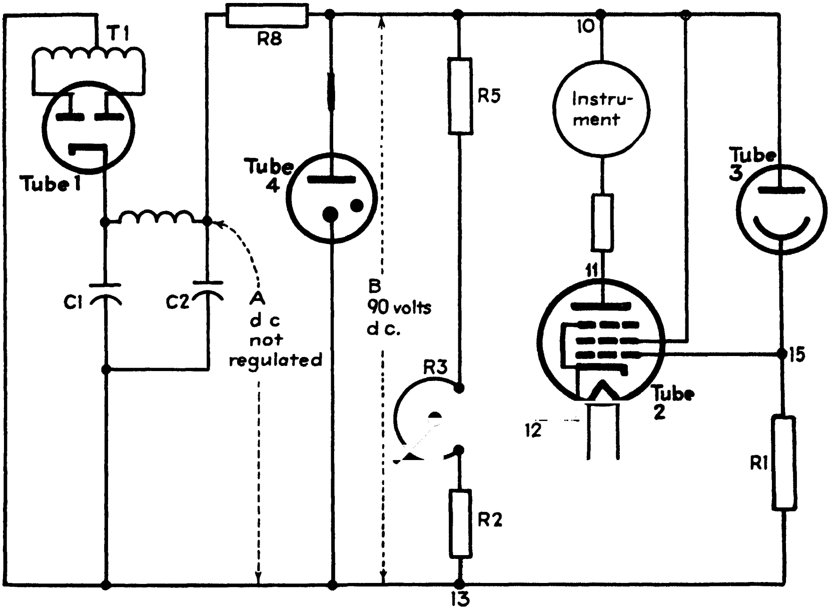

FIG. 1-22.

The 90 volts steadily maintained at *B* in Fig. 1-22 causes current to flow from 10 through the instrument to anode 11, through tube 2 to cathode 12, through *R*3 and *R*2 to 13. The amount of tube 2 current is controlled by the potential at 15, which is the control grid of tube 2. Although tube 2 is a pentode (a five-element tube with three grids), notice that the upper grids are connected to constant-potential points 12 and 10. Although these extra grids give superior performance to this kind of tube, they are disregarded in our study of circuit operation.

In Fig. 1-22, phototube 3 and *R*1 perform the same as in Fig. 1-21. When receiving no radiant energy (such as light or heat radiated from a hot object), phototube 3 passes almost no current, so grid 15 is more negative than cathode 12; under this condition *R*3 is adjusted so that 0.5 ma flows through tube 2. However, as the object becomes red or white hot, much radiant energy reaches phototube 3 and appreciable current flows from 10 through phototube 3 and *R*1, which raises the potential at 15 and causes tube 2 to permit more current to flow through the indicating instrument. The vacuum-type phototube and the pentode tube 2 assure more constant performance during months of continuous operation; each change of temperature observed by the phototube produces a definite change in current at the instrument, to give correct temperature readings at various parts of the scale.

7. Operating a Direct-current Motor on Alternating-current Power Supply

By setting up the proper circuits and by using the thyratron tubes as converters, d-c motors can be operated from an a-c power supply. The complete circuit can be broken down into two basic supply circuits: the armature and the field. Auxiliary circuits are added to shift the phase angle of thyratron firing which in turn varies the available armature and field voltages from nearly zero to a maximum. An additional circuit is used to obtain current limit and full field during starting periods. A compensating circuit is added to prevent speed drops during load changes.

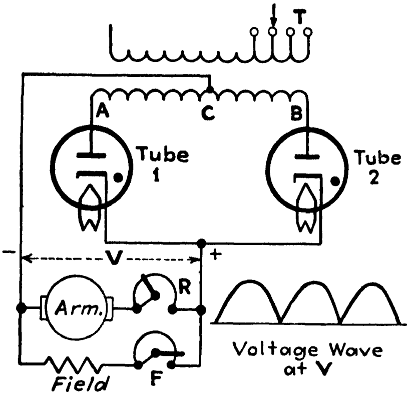

FIG. 1-23.

The operation of a d-c motor from an a-c power supply is quite different from the preceding examples of electronic control. If a simple two-tube rectifier is used as shown in Fig. 1-23, the motor speed cannot be controlled except by a series rheostat *R*, a field rheostat *F*, or by changing the tap of transformer *T*. Tubes 1 and 2 have no grids, so they act merely as valves. During the half-cycle when the transformer winding is more positive at *A*, the voltage between *A* and *C* forces current to flow through tube 1, through the motor, and back to *C*. During the next-half-cycle, when the transformer winding is more positive at *B*, the voltage between *B* and *C* forces current to flow through tube 2, through the motor, and back to *C*. Since tubes 1 and 2 are vapor-filled, the voltage drop from anode to cathode is only about 15 volts; the remainder of the voltage (*A* to *C* or *B* to *C*) appears across the load at *V*. These tubes cannot control or change the amount of voltage at *V*.

Controlling Motor Speed by Thyratrons

In Fig. 1-24, two rectifier tubes again supply pulsating direct current to a motor armature. These tubes are thyratrons and can be controlled by their grids so as to change the average voltage applied to the motor armature, and thereby control the motor speed. Meanwhile the motor field receives its constant current through a separate rectifier, tube 3.

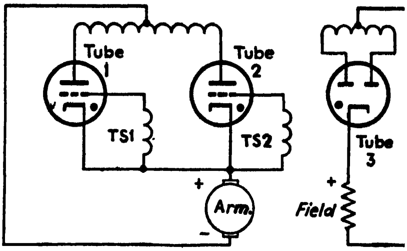

FIG. 1–24.

Since tubes 1 and 2 are of the vapor-filled type (so as to be able to conduct the large current required by such a motor load), the *instantaneous amount* of current flowing through these tubes at any instant depends entirely on the a-c supply voltage and the motor load circuit. The grids can merely "tell" each tube when to start passing this current; that is, the grid can prevent the tube from firing or conducting anode current, until some desired point in each wave of applied a-c anode voltage. For example, Fig. 1-26 shows the a-c anode voltage that is applied to tubes 1 and 2. The grid voltage (supplied by transformers $TS1$ and $TS2$ in Fig. 1-24) is nearly in phase with the anode voltage; that is, the curve of grid voltage crosses the cathode line at A, almost the same spot where the anode-voltage curve meets the cathode line. As a result, the tubes begin to conduct current at point A in each half-cycle, so voltage is applied to the motor armature during nearly the entire time.

However, if the curve of grid voltage is phase-shifted (by a circuit explained below) or moved to the position shown in Fig. 1-28, the grid is more negative than the cathode during the first part of each half-cycle, from B to C and from D to E, so the tubes are prevented from conducting anode current until points C and E. Voltage is applied to the motor armature during the shaded part of each half-cycle. The average value of this jagged voltage wave is G (as read on a d-c voltmeter). Notice that G is a smaller amount of voltage than F, as read on a d-c voltmeter, in Fig. 1-26.

If we now phase-shift the grid voltage still farther, as shown in Fig. 1-30, until the grid-voltage curve crosses the cathode line quite late in the half-cycle, the tubes do not begin to conduct until point J; the voltage applied to the motor armature during the small shaded portion has a very low average value H.

Phase-shifting Circuit

The phase shifting of grid voltage (of tubes 1 and 2 in Fig. 1-24, by means of transformer windings *TS*1 and *TS*2) is accomplished by the circuit in Fig. 1-25. Here we find the primary winding *TP* of the grid transformer, connected in the center of a bridge circuit, which receives a-c power from transformer winding *KM* (from the same source that supplies anode voltage to tubes 1 and 2). Connected between *K* and *M* are a constant resistance *R* and a reactor *X*; here *X* is in the form of a solenoid whose iron armature or core can be withdrawn from the magnet coil. Withdrawing the core decreases the amount of iron that is effective. With less iron, the reactor has less inductance; that is, it is less able to prevent the flow of alternating current through its winding.

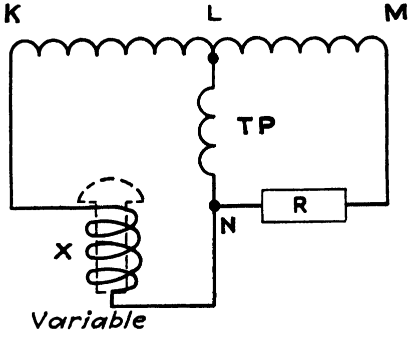

FIG. 1-25.

Starting with the core withdrawn from the solenoid *X* in Fig. 1-25, the resulting small inductance of *X* permits considerable current to flow through *X* and resistor *R*. This condition is shown in the vector diagram of Fig. 1-27; current *I* nearly in phase with the supply voltage *KM;* a large voltage drop *IR* across the resistance, a small voltage drop *IX* across the solenoid. Connected between junction *N* and midtap *L* is the grid transformer, whose primary voltage *TP* fits in the vector triangle as shown in Fig. 1-27. The secondary winding *TS*1 is connected so that its output voltage (at the grid of tube 1) lags behind the supply voltage by the small angle *Z*. This condition produces the wave shapes shown in Fig. 1-26.

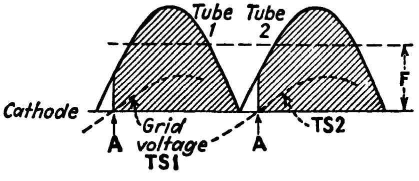

FIG. 1-26.

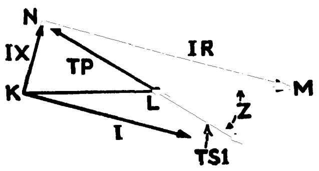

FIG. 1-27.

If the core of solenoid *X* (in Fig. 1-25) is inserted part way into the coil, the inductance is increased until the voltage drop across *X* is as large as the voltage drop across *R*, as shown in Fig. 1-29. Here *TS*1 is seen to lag 90 deg behind the supply voltage. This produces the wave shape shown in Fig. 1-28. Notice that this increase of inductance of X has phase-shifted or retarded the grid voltage curve of tubes 1 and 2, thereby decreasing the average motor voltage from F (Fig. 1-26) to G (Fig. 1-28). Similarly, further insertion of the solenoid core produces the conditions of Figs. 1-30 and 1-31, reducing the motor armature voltage to H. With this method, the speed of a motor is easily controlled by moving a solenoid core, such as occurs in the automatic control of tension when reeling wire.

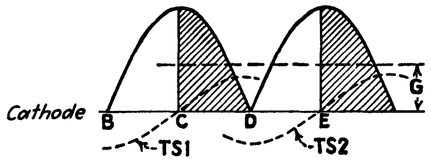

FIG. 1-28.

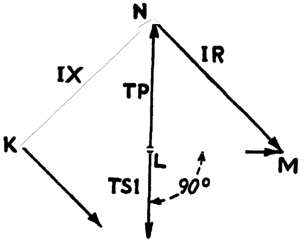

FIG. 1-29.

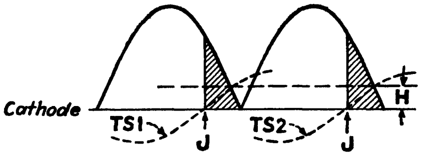

FIG. 1-30.

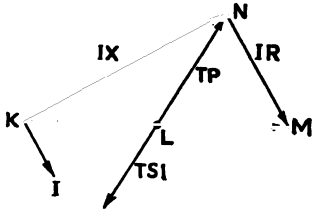

FIG. 1-31.

Control by a Saturable Reactor

In many recent phase-shifting circuits, the movable-core reactor of Fig. 1-25 is replaced by a saturable reactor, a device whose amount of inductance is easily changed without moving any part. Instead of physically withdrawing the iron, we change the inductance of the saturable reactor by means of saturating its iron. To make this possible, the saturable reactor includes not only a main a-c winding, but also a separate winding through which direct current may flow. Figure 1-32 shows such a reactor (SX) substituted in the phase-shifting circuit of Fig. 1-25.

Figure 1-32 includes a small rectifier tube A, whose output current passes through the d-c winding of saturable reactor SX (although other d-c sources may be used for this purpose). With rheostat VT turned to insert all its resistance, the amount of direct current flowing is too small to affect SX, which therefore has maximum inductance. However, when the rheostat is turned, increasing the flow of current in the d-c winding of *SX*, the inductance of *SX* decreases, producing the condition shown in Fig. 1-30. As we increase this d-c saturation current further, the decreasing inductance of *SX* advances the curves of grid voltage, producing first the conditions of Fig. 1-28, and then Fig. 1-26. Notice that an increase of direct current in *SX* produces a corresponding increase of average voltage at the motor armature.

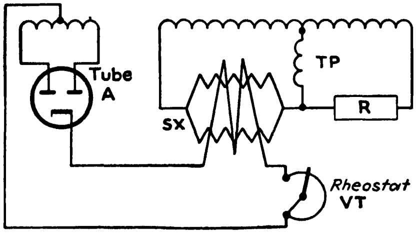

FIG. 1-32.

The iron-core saturable reactor *SX* is so designed that the iron loses its inductive effect when even a few milliamperes of direct current flow through the many turns of its saturating winding. This small amount of current can easily be conducted and controlled by a small vacuum tube, and we next study the motor-control circuit wherein high-vacuum tubes are used in place of rheostat *VT* of Fig. 1-32.

8. All-tube Regulation of Direct-current Motor-armature Voltage

When we wish to adjust the speed of a d-c motor and then hold that speed constant, we know that the voltage supplied to the motor armature must be accurately regulated. This regulation is accomplished by the circuit of Fig. 1-33, which combines the circuits of Figs. 1-24 and 1-32 with an additional pair of vacuum tubes (*C* and *D*). We shall see that, if the armature voltage changes, tubes *C* and *D* will immediately cause tubes 1 and 2 to restore the armature voltage to normal.

To obtain the needed accuracy of tube response, Fig. 1-33 first supplies a closely regulated source of d-c voltage. At the left side of Fig. 1-33, the rectified output of tube *A* is filtered by reactor *X* and capacitor *C*1; voltage-regulator tubes (*G* and *B*) (previously described in Fig. 1-22) are used to hold constant voltage between points 5 and 7. Tube *G* is designed to hold 75 volts between points 5 and 6; duplicate tube *B* similarly holds 75 volts between points 6 and 7. The 150 volts between points 5 and 7 is applied to the voltage divider *R*2, *R*3, and *R*4. Notice that this divider is not connected to point 6.

Before the motor can start, the tubes must be given sufficient time to become hot. This heating time is assured by a 5-min time delay relay whose contacts close the motor field circuit (see *TDR* in Fig. 1-33). The flow of field current picks up *FFR* (field-failure protective relay) which closes its contact in the motor-starting circuit. To start the motor, contactor *LE* connects the motor armature to the d-c output of tubes 1 and 2.

The desired motor speed is selected by turning potentiometer *P*3 (whose slider is connected to the cathode of tube *C*). The resulting motor speed depends on the armature voltage (between points 24 and 7); part of this armature voltage appears across *R*6 of a voltage divider and is connected to grid 2 of tube *C*. Tube *C*, after "being told" at its cathode what motor speed is desired, is kept informed at its grid as to whether the motor speed is correct.

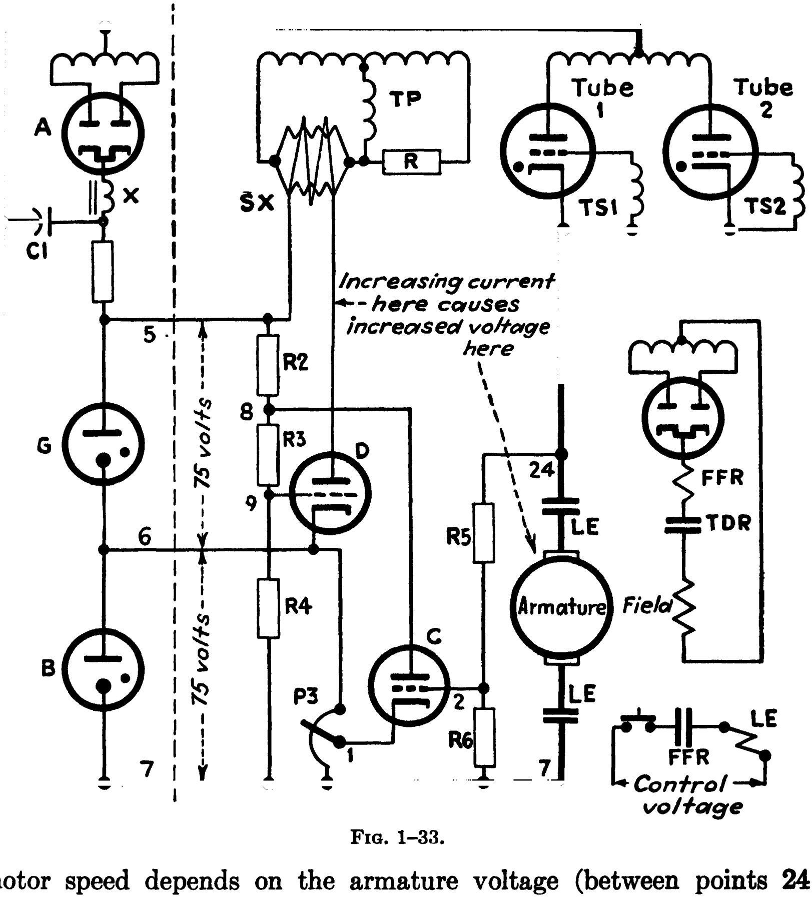

FIG. 1-33.

Watching the Circuit Regulate the Armature Voltage

Suppose the speed dial (*P*3 in Fig. 1-33) is set at a high-speed position, where 65 volts exist between slider 1 and point 7. If the armature voltage is too low to produce this desired speed, the portion of the armature voltage across *R*6 will be much less than 65 volts; grid 2 is much more negative than cathode 1, so no anode current flows in tube *C*.

Notice that the tube *C* anode is connected to a voltage divider at point 8; resistors *R*2, *R*3, and *R*4 have such values that the voltage drop across *R*4 is about 75 volts when there is no tube *C* current; therefore the grid potential of tube *D* is at a potential equal to that of point 6 (cathode of tube *D*). Having no grid bias, tube *D* conducts enough anode current to saturate *SX* and thereby increase the average voltage which tubes 1 and 2 apply to the motor armature.

When the motor-armature voltage increases, the voltage across *R*6 increases also and raises the potential of grid 2, thereby "turning on" tube *C*. Notice that any tube *C* current flows from point 5 through *R*2, anode to cathode of tube *C*, through *P*3 to point 7. As the tube *C* current increases, a larger voltage drop appears across *R*2, with a corresponding decrease of voltage across *R*4, which lowers the potential of point 9, grid of tube *D*. We see that turning on tube *C* turns off tube *D*, thereby decreasing the saturation of *SX*, turning off tubes 1 and 2 and decreasing the voltage applied to the motor armature.

When we wish to decrease the motor speed, we turn slider *P*3 toward point 7. This action lowers the cathode potential at 1, increases the current flowing through tube *C* and *R*2, decreases the current flowing through tube *D*, and thereby phase-shifts tubes 1 and 2 to produce a lower armature voltage. With this new setting of *P*3, the circuit continues to regulate or phase-shift tubes 1 and 2 until the grid of tube *C* reports that the motor armature voltage has reached the desired value.

Voltage Regulation by Combined Armature and Field Control

Although some tube-operated motors are controlled only by the armature-voltage circuit just described, greater speed range is provided by the circuit of Fig. 1-34, which gives additional speed control by weakening the motor field. Notice that the armature-voltage control (left-hand portion of Fig. 1-34) has already been described. The motor field receives its direct current from a separate pair of thyratrons (tubes 3 and 4), which are phase-shifted in the same way as the armature tubes (1 and 2). The field-voltage-control circuit is a duplicate of the armature-control portion, and operates from the same d-c supply (points 5, 6, and 7). Tube *CC* balances the fixed portion of the field voltage (between points 12 and 7) against the desired field voltage as set by *P*5. An increase of tube *CC* current causes a larger voltage drop across *R*12 of the voltage divider; the lowered potential at 19 decreases the current through tube *DD* and the saturating winding of *SXF* and thereby decreases the voltage that tubes 3 and 4 apply to the motor field.

Speed controls *P*3 (armature) and *P*5 (field) are mounted on a common shaft, operated by a single dial. The right-hand half of *P*3 and the left half of *P*5 have almost zero resistance. Turned counterclockwise, the dial produces low motor speed, for the armature voltage is almost zero while the motor has full field. (Tube *C* is full ON, tube *CC* is full OFF.) Turning the dial clockwise gradually increases the armature voltage but has no effect on the field voltage until the mid-point is reached. Turning beyond mid-point causes no further increase in armature voltage but weakens the field, causing further increase in motor speed.

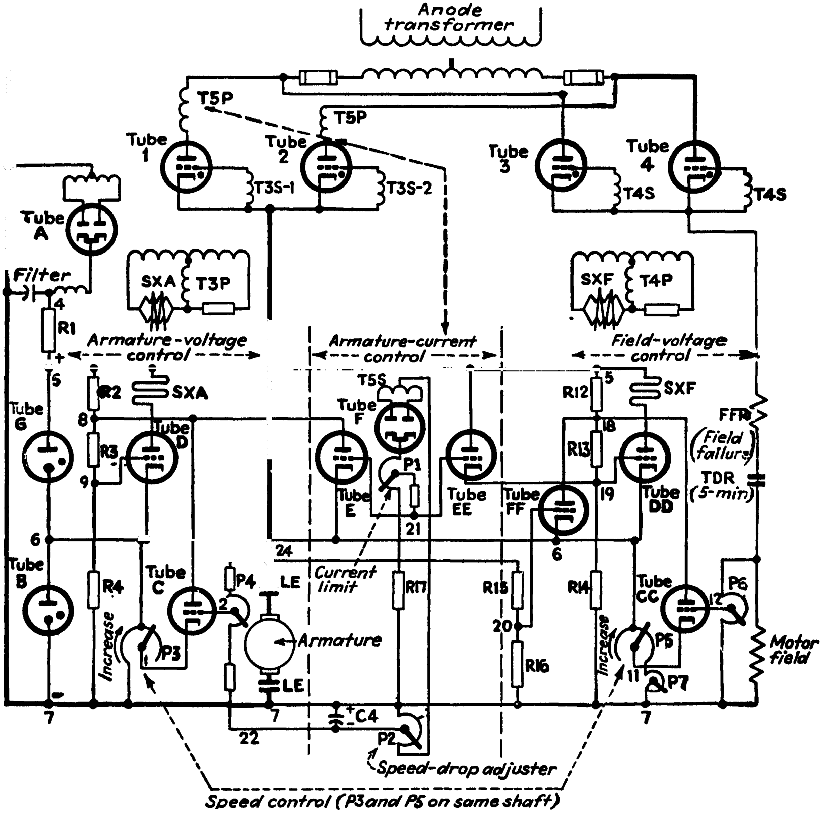

FIG. 1-34.

Operation with weakened field adds the problem of higher voltage generated by the motor armature if the speed dial is suddenly lowered from the high-speed position. Tube *FF* is added to the field-voltage-control circuit; its grid is connected to resistors *R*15 and *R*16 across the motor armature. As long as the armature voltage is less than 300 volts (for a 230-volt motor), there is much less than 75 volts across *R*16; the grid of tube *FF* is quite negative and no anode current flows. However, if sudden field strengthening causes the motor to generate more than 300 volts (since the motor does not "pump back" through tubes 1 and 2), the increased voltage across *R*16 raises the grid potential of tube *FF* so that current flows through tube *FF* and *R*12. This decreases the current of tube *DD* and decreases the field current merely enough to keep the armature voltage below the desired limit.

Current-limit Control of the Direct-current Motor

The circuits in Fig. 1-34, discussed thus far, all have responded only to armature voltage or field voltage. In addition, most recent electronic motor controls respond to the amount of motor-armature current, so as to prevent a flow of current greater than some present amount. Such armature-current control is included in the central portion of Fig. 1-34. So as to know how much armature current is flowing, two transformer primary windings (*T*5*P*) are added above tubes 1 and 2; when current flows through tubes 1 and 2, a corresponding current (a-c) flows in the transformer secondary (*T*5*S*). Tube *F* rectifies this current into pulsating direct current, which flows down through *P*1, *R*17, *P*2, and back to the center tap of *T*5*S*. When there is no motor-armature current, point 21 is at the potential of point 7. However, when current flows through *T*5*S*, and tube *F* (in direct proportion to the armature current), this current causes a voltage drop across *R*17; the potential rises at *P*1 and point 21 (the grid of tube *E* and tube *EE*).

If *P*1 is adjusted to give a "current limit" of about 150 per cent of motor full-load current, tubes *E* and *EE* have no effect at lesser armature currents. However, with more than 150 per cent armature current, both *E* and *EE* come into action. Tube *E* draws additional current through *R*2 so that tube *D* decreases the saturating current of *SXA;* resulting decrease of armature voltage also decreases the armature current. However, tube *EE* gives an opposite action; instead of decreasing the field voltage, *EE* is connected so its current passes through *R*14, thereby raising point 19, increasing the field voltage and current. We see that excessive armature current causes tube *E* to turn off tube *D* (and decrease armature voltage), but makes tube *EE* turn on tube *DD* (and increase the field current). This action limits the inrush current when starting the motor, and also assures full-field starting even though the speed dial (*P*5) is in a high-speed weak-field position.

Preventing Speed Drop during Load Changes

The circuit of Fig. 1-33, while holding constant voltage at the motor armature does not assure constant speed during changes of motor load. We know that a d-c motor's speed usually changes when the load changes, because of the internal voltage drop (*IR* drop) of the motor. However, Fig. 1-34 includes a "speed-drop adjuster" at the bottom of the armature-current control. The voltage across *P*2 increases as the motor load increases; such increase causes the *P*2 slider (point 22) to be more negative than the top, point 7. This *P*2 voltage is placed in series with *P*4 (across the motor armature) so that, as the increasing motor load lowers the potential at point 22, the grid of tube *C* is likewise lowered. Even though the armature voltage has remained constant, the increased motor load causes a decrease of the tube *C* current, which causes tube *D* and tubes 1 and 2 to apply greater voltage to the motor armature. By adjusting *P*2, the motor speed is made to remain constant despite load changes.

The circuit of Fig. 1-34 demonstrates a combination of high-vacuum tubes and vapor-filled tubes to produce better motor performance. Both types of tubes are made to give gradual stepless variation of output; the vapor-filled tubes require the use of phase shift of the grid voltage to produce such variable output.

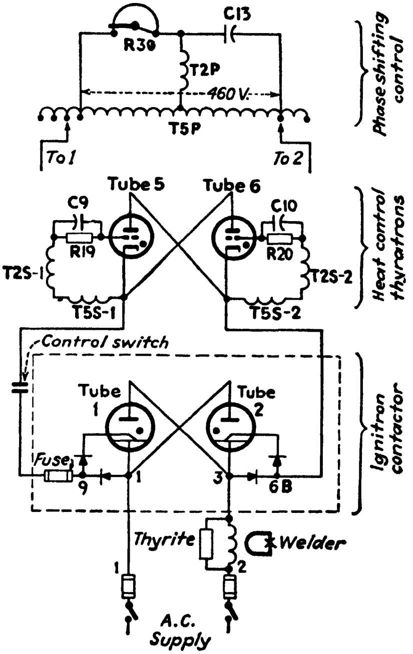

FIG. 1-35.

9. Phase-shift Heat Control of Resistance Welders

Another important use of phase-shifted vapor-filled tubes is in the heat control of welders. Figure 1-35 shows two thyratron tubes (5 and 6) arranged to control and fire ignitron tubes 1 and 2, which are used in an ignitron contactor previously described (Fig. 1-20). By itself, the ignitron contactor will apply either full voltage or no voltage to the welding transformer; the welder produces full heat at the weld, or no heat. By adding thyratrons 5 and 6, the ignitrons are made to give stepless variation of the voltage applied to the welding transformer, producing gradual heat control of the welder.

Current may flow through tube 5 only when the a-c supply line (2) is positive; this current flows from 2 through the welding transformer to 3, through the metallic rectifier to 6*B*, through tube 5, the control switch and the fuse to point 9, into the ignitor of tube 1, to line 1. We see that tube 5 fires ignitron 1; tube 6 fires ignitron 2 during the other half-cycle.

In Fig. 1-35, the grid circuit of tube 5 is a duplicate of the tube 6 circuit. Each grid circuit includes two transformer windings instead of the single winding shown in Fig. 1-24. The voltage waves in the grid circuit of tube 5 are shown in Fig. 1-36. We see that *T*5*S*-1 is the secondary voltage of an ordinary transformer, connected so that its voltage forces the tube 5 grid negative while the anode of tube 5 is positive; in this way *T*5*S*-1 produces a "hold-off" voltage which prevents tube 5 from firing.

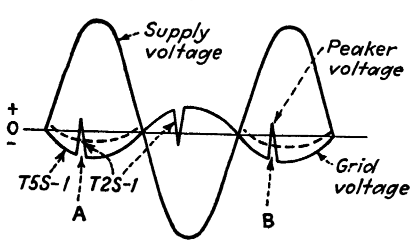

FIG. 1-36.

Control by a Peaking Transformer

The other transformer (*T*2*S*-1 in Fig. 1-35) is seen to produce a narrow voltage peak in Fig. 1-36. This peak is high enough to force the tube 5 grid positive for just a small part of the half-cycle; this brief voltage peak fires tube 5. If we can change the position of this peak, we also change the point in the half-cycle where tube 5 fires. By phase-shifting the voltage applied to this peaking transformer (*T*2), we can gradually vary the average voltage which ignitrons 1 and 2 supply to the welder.

Transformer *T*2 is specially designed with very little iron in its core, so that the iron is saturated during most of each half-cycle. When the transformer's magnetizing current reverses, there is a sudden short-time reversal of flux in the iron, producing voltage in the form of a narrow peak in each of the two secondary windings. The position of this peak is definitely fixed with respect to the a-c voltage wave applied to the primary winding. Therefore, to move this peak and thereby change the firing point of tubes 5 and 6, we must change or shift the phase of the a-c voltage supplied to primary (*T*2*P*).

The circuit for shifting the phase of *T2P* appears at the top of Fig. 1-35. It is similar to Fig. 1-25 except that a fixed capacitor (*C*13) replaces a fixed resistor, while a variable resistor (*R*30) is used instead of a variable inductance. When *R*30 is short-circuited, the voltage peak of *T2S* occurs quite early in each half-cycle, and fires tube 5 at *A* and *B*, as shown in Fig. 1-36. The resulting flow of current to the welder is nearly a complete sine wave.

When part of *R*30 resistance is inserted, the *T2S*-1 voltage peak occurs later in the half-cycle, as shown in Fig. 1-37; welder current flows for a smaller portion of the half-cycle, producing partial heat at the weld. Figure 1-37 also shows the purpose of capacitor *C*9 (shown with tube 5 in Fig. 1-35). To prevent tube 5 from firing accidentally at *A* where the grid voltage is zero, *C*9 is charged by grid current while *T*5*S*-1 is positive. This *C*9 charge drives the tube 5 grid more negative, at *B*, and helps prevent tube 5 from firing until *C*.

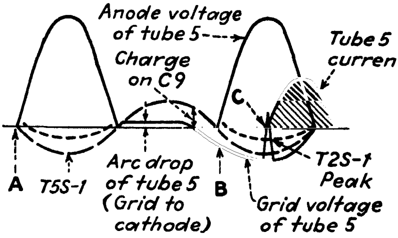

FIG. 1-37.

With all of *R*30 resistance inserted, Fig. 1-38 shows that the voltage peaks of *T2S* are delayed so that tubes 5 and 6 fire the ignitrons very late in each half-cycle. The resulting current flow produces low heat at the welder.

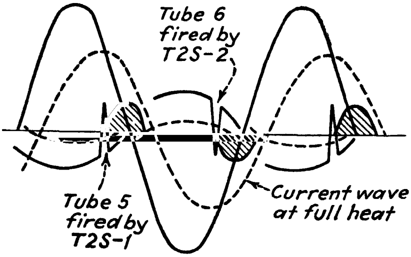

FIG. 1-38.

A thorough understanding of the foregoing fundamental principles of electronic circuit operation should be acquired before proceeding to the chapters that follow dealing with the installation, maintenance, and servicing of various types of specific equipments.

CHAPTER 2

GENERAL CONSIDERATIONS IN INSTALLING AND MAINTAINING ELECTRONIC CONTROL

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The first consideration in installing or maintaining any electronic equipment is to become acquainted with the information supplied by the manufacturer. This information is supplied in two forms: the diagram of connections and the instruction book. The completeness of this information varies with the class of equipment. In general, the instruction books for established, general-purpose standard-line panels are more complete than those for special-purpose panels. Regardless of the completeness of the instruction book, all manufacturers supply complete detailed diagrams, which usually give a tremendous amount of information and should be read carefully and understandingly.

Symbols

The information given on diagrams is often in symbolic form, requiring an understanding of the symbols used. The NEMA and the ASA have committees working continuously to establish unified symbols, and all large manufacturers abide by the standards established for magnetic control. The picture, however, is slightly confused in the case of industrial electronic control, largely because communication engineers have entered this field and brought with them some of the communication symbols that have not been common in the industrial and power field. Most large manufacturers use the industrial and power symbols when building equipment for this field whether it is electronic, magnetic, or a combination of both.

Because the electronic equipment in use today is built by a large variety of manufacturers, installation and maintenance men will encounter both types of symbols and should be familiar with them. The accompanying table shows the symbols in common use today as well as several obsolete and newly proposed ones. It also includes the recently adopted ASA tube-element symbols. These elements can be

DIAGRAM SYMBOLS

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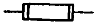
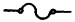
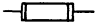
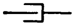
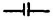
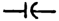
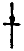
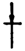
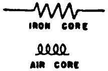
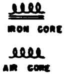
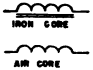
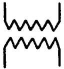
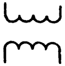
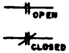
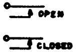
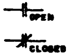
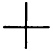
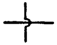
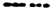
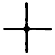
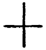
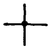
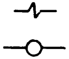
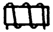
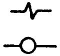
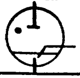
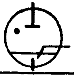
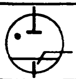
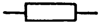
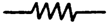
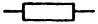
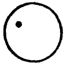
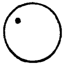
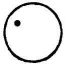
FUSE				CAPACITOR			
DRY PLATE RECTIFIER				REACTOR			
DIRECTLY HEATED CATHODE (FILAMENT)				TRANSFORMER			
INDIRECTLY HEATED CATHODE				CONTACTS			
COLD CATHODE				WIRE CROSS (NOT CONNECTED)			
GRID				WIRE CROSS (CONNECTED)			
ANODE (PLATE)				RELAY COIL			
IGNITRON				RESISTOR			
GAS-FILLED TUBE							

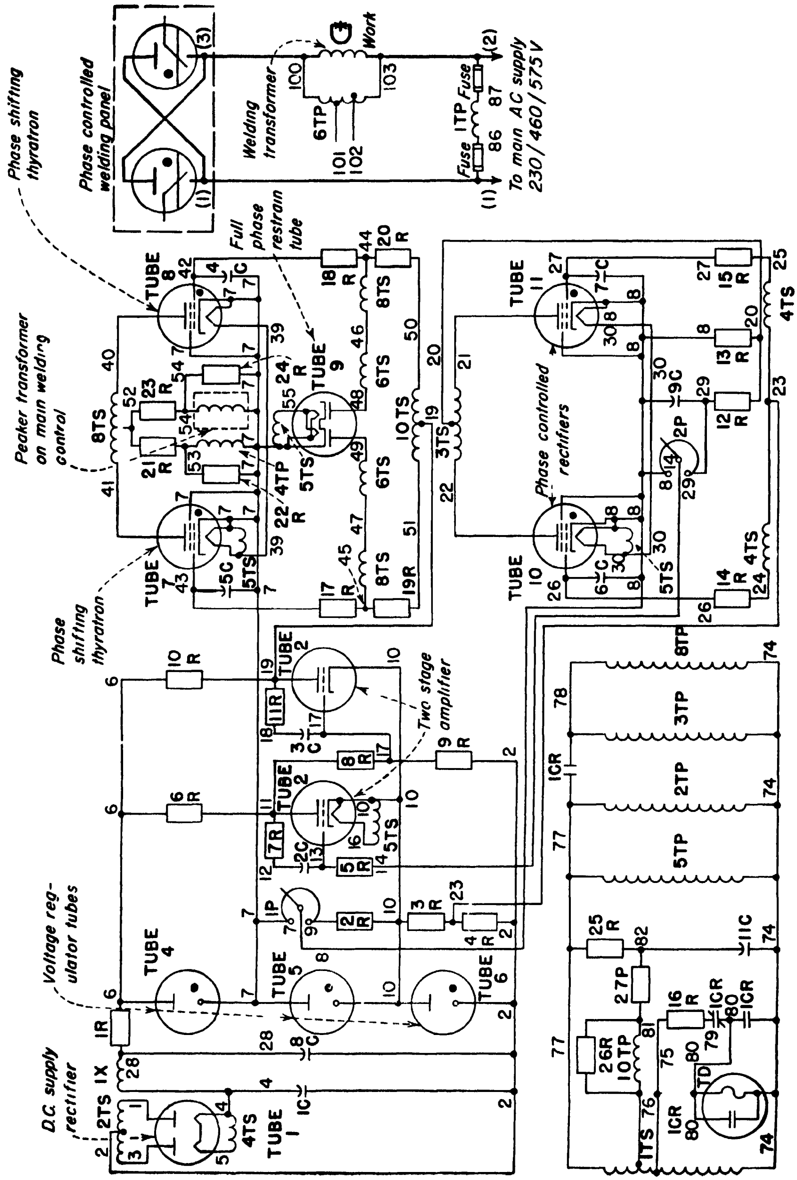


Fig. 2-1. Elementary diagram of a voltage-regulator control with functional devices separated.

combined to represent any type of tube used in industrial apparatus today.

Diagrams

The wiring diagram, furnished with practically all equipment manufactured by firms acquainted with industrial requirements, has five subdivisions. These may be on five different pieces of paper or prints, or they may be all on one drawing. These subdivisions are

1. Elementary diagram.
2. Main diagram.
3. Interconnection diagram.
4. Material list and specifications.
5. Installation and adjustment notes.

The elementary diagram shows the parts and circuit elements as they are used in the circuit. Devices, such as relays, contactors, transformers, and switches that have functions in different circuits are separated, with individual parts located in that portion of the diagram where they are used. Each part of the same device has an identifying number and letter which indicate that all parts are on the same device. An example of this is shown in Fig. 2-1. Dotted lines are sometimes used to tie the parts of a single device together.

The elementary diagram is the one that the engineer makes when he plans the equipment for a given job. It is also the one to be used by anyone else to figure out how the panel works. It should be referred to in trouble-shooting operations. With it, the sequence of operations can be traced and, by noting from the operation just where the failure occurs, the faulty relay contact or burned-out winding can be located. In other words, if understood, this is the most useful diagram both before the equipment is built and after it is installed.

Panel Diagram

The main, or panel, diagram shows the relative physical location of the wiring on the panel. The relay coils and contacts are shown together, and all the windings of a transformer are grouped as they are in the transformer. This diagram is made for the man building and wiring the panel. It shows him just where to mount the apparatus and where to run the wires. The terminal boards are shown in their relative location. The entire panel is shown in either back or front view, and the top of the diagram is so labeled. The one exception to usual drafting practice is that the wires are never shown dotted whether they are on the viewed side or not. A dotted line means an optional connection and should always be accompanied with a note telling exactly under what conditions it should be used. The panel diagram has one other very important function: to help the

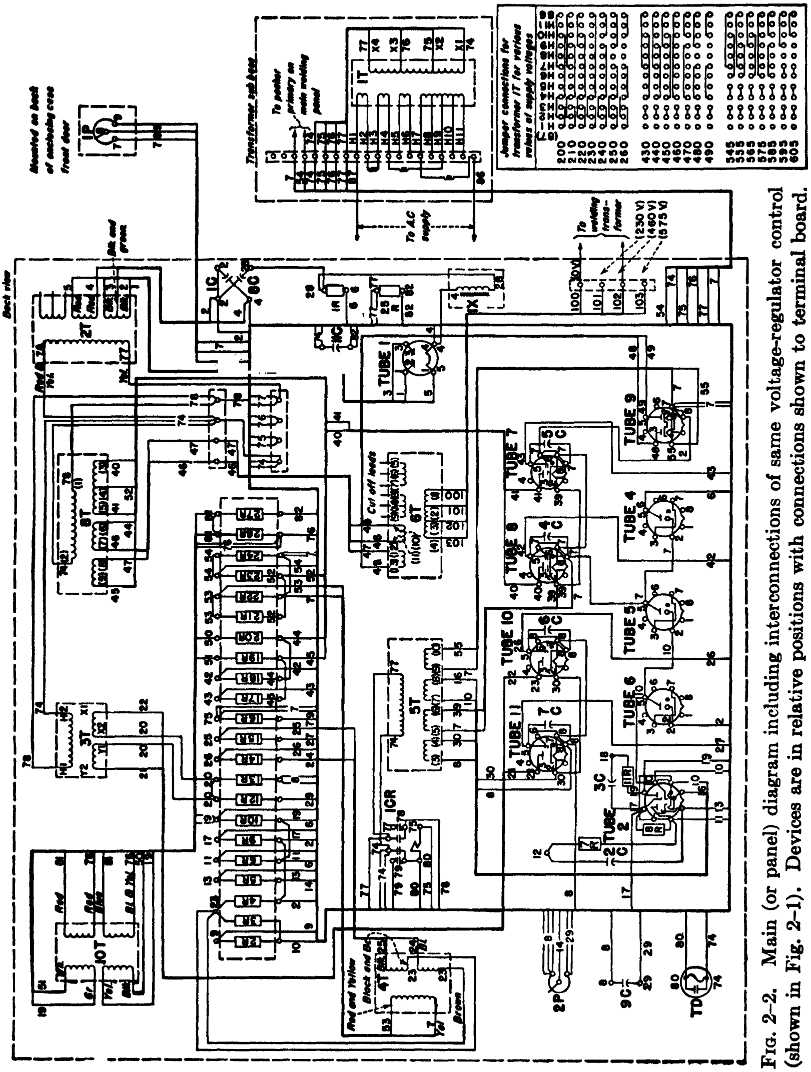


FIG. 2-2. Main (or panel) diagram including interconnections of same voltage-regulator control (shown in Fig. 2-1). Devices are in relative positions with connections shown to terminal board.

maintenance man find the device or wire on the panel after he has determined from the elementary what change he should make. The device symbols and numbers, as well as the wiring-point numbers, make this identification very simple.

The interconnecting diagram is produced for the installation man to show him just how to wire the control to the accessories and to the machine that is to be controlled. Many times the panels will be indicated as blank squares with only the terminal boards or outgoing connections shown. The engineer making this diagram must know not only about the control panel but also about the terminal markings on the machine to be controlled and all other parts of the system. When the system is simple, the interconnections are often shown on the same drawing as the panel diagram. That is, the accessories and the machine to be controlled are shown connected to the terminal board of the panel diagram. Figure 2-2 is such a diagram.

Many manufacturers include on the diagram a list of the parts, giving their specifications. This assists in checking the panel for defective apparatus and also serves as a parts list when ordering replacements. If the diagram is split up, this list is usually on the elementary diagram.

Those things which cannot be shown by symbols on diagrams are usually included as a series of notes covering such items as changes to be made when changing line voltage, and installation adjustments of a simple nature. Be sure to read every note on the diagram before starting the installation and then read and check them all again before applying power. For more complete information, see the instruction book supplied with the panel.

Meters and Test Equipment

The meters and test equipment required for installation and maintenance depend on several factors. These include the number of equipments involved, the type of equipment, and the importance of service continuity to the productivity of the plant. Here is a list that covers practically all types of industrial electronic equipment. It is given in approximate order of importance.

Multimeter or Analyzer

This instrument must read a-c and d-c volts with at least 5,000 ohms per volt. It should have facilities for reading resistance values approximately. A number of such meters (Fig. 2-3) are on the market and range in price from $15 to more than $100, depending on ranges and accuracy provided.

Cathode-ray Oscilloscope

This should be portable, simple to operate, and modified (Fig. 2-4) to read d-c voltages directly on the plates. A 2- or 3-in. tube is ideal

FIG. 2-3. Three multimeters for reading a-c and d-c volts, milliamperes, and ohms. Left to right, they are Triplett Electrical Instrument, Precision Apparatus, and General Electric.

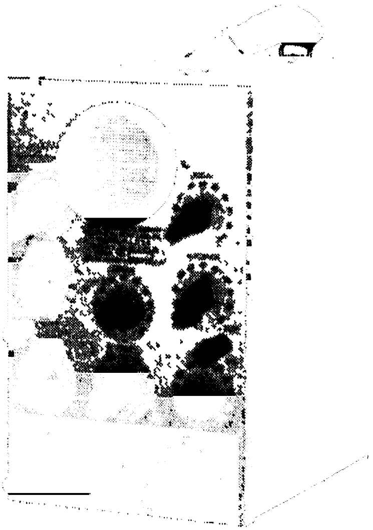


FIG. 2-4. Cathode-ray oscilloscope, built by DuMont Laboratories, has been modified to read d-c voltages. The tube provides a 3-in. screen in this portable unit.

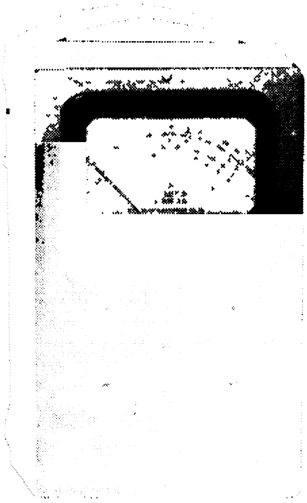


FIG. 2-5. Vacuum-tube voltmeter (built by RCA) which does the same job as a multimeter with better performance and accuracy. Reads a-c and d-c volts, and ohms.

for maintenance and trouble shooting. Oscilloscopes using a 5-in. tube are useful in a laboratory but are too heavy and large for use on the job. Several good models are on the market now, but many must be modified to read d-c voltages. This modification is an absolute necessity for work on industrial electronic equipment. The cathode-ray oscilloscope is one of the most versatile and perhaps the least understood instrument available.

Vacuum-tube Voltmeter

This instrument in its present commercial form (Fig. 2-5) will do better the same work done by the standard multimeter. It costs more and must be connected to a-c power, which sometimes limits its usefulness and flexibility. On many low-energy and high-impedance circuits, it is the only instrument that can be used successfully.

Split-core Current Transformer and Ammeter or Hook-on Meter

Either the current transformer and meter or the combined hook-on type of instrument is essential in checking the line current of resistance-welding machines or other a-c loads associated with electronic control. The instrument should be provided with a pointer-stop so that current values of short duration can be measured.

Single-element Magnetic Oscilloscope

This instrument (Fig. 2-6) is ideal for reading accurately peak values of current even if only of half-cycle duration. It is also the best instrument for determining the balance, or magnitude of unbalance of a-c transient currents.

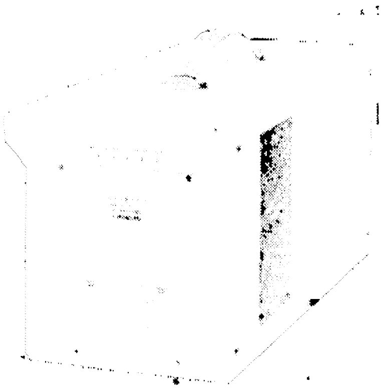


FIG. 2-6. Single-element magnetic oscilloscope used for accurate measurement of peak currents of short duration.

Radio Tube Checker

This instrument is useful and worth while in large plants where considerable electronic control equipment is used. This is limited to radio receiver tubes and must be kept up to date to take care of new tubes as they are put out by the tube manufacturers.

Industrial Tube Checker

This is a tube tester for mercury- and gas-filled tubes designed to measure the arc drop of the tube while passing short pulses of current

(Fig. 2-7). The arc drop of a thyratron or phanotron is a measure of the cathode emission, which is the expendable part of a thyratron or phanotron.

Handling

In general, electronic control apparatus is precision equipment and should be considered as such when it is being handled or stored. The tubes should be kept where the handling and possibility of damage are at a minimum. To avoid condensation of moisture on the panels, they should be stored in a dry place where the change in temperature is slight.

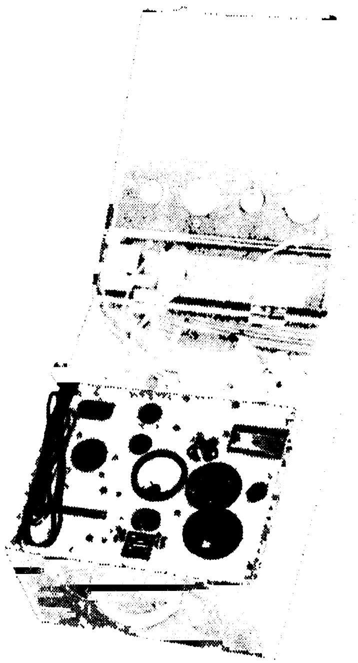


Fig. 2-7. Industrial tube tester for checking the performance of mercury- and gas-filled tubes.

The moisture and dust-laden air, usually found around new buildings where concrete or plaster is being mixed and used, has been found to be disastrous to the high-resistance circuits of electronic control panels.

Domestic packing methods are not weatherproof nor even weather-resistant. When the equipment is packed in excelsior, it is protected from the direct action of the weather, but the excelsior acts as a sponge and keeps the equipment surrounded by moist air which will later be condensed on the panel with each heating and cooling cycle.

When the panels are unpacked ready for installation, they should be inspected immediately for broken or missing parts. Any shortages or defects should be reported at once so that steps can be taken for replacement. The instructions and diagrams, after installation, should be kept in the files of the maintenance department where they are readily available when needed. Further, it is absolutely essential that diagrams be kept up to date. All replacements and substitutions of tubes, resistors, capacitors, etc., and circuit revisions should be noted on all drawings pertaining to specific equipment. Failure to do so may prove costly in emergencies.

CHAPTER 3

THE CATHODE-RAY OSCILLOSCOPE—WHAT IT IS, HOW TO USE IT

By O. W. LIVINGSTON

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The cathode-ray oscilloscope should be to the serviceman and engineer what the X ray is to the doctor. It is a quick, convenient way of checking conditions that cannot be checked by any other direct means. In a few seconds, one is able actually to "see" the voltage across a given part of a circuit, which may permit very rapid diagnosis of a faulty condition.

The purpose of this chapter is to explain the fundamentals of the use of this instrument for the installation and maintenance of industrial electronic equipment.

Most commercially available cathode-ray oscilloscopes consist of a rectangular metal case which contains the cathode-ray tube, power supplies, timing circuit, and amplifiers. The screen end of the cathode-ray tube is generally visible from one end of the enclosure, on which are mounted the various control knobs and switches. Figure 3-1 shows the operating end of a typical oscilloscope. Although different models vary in size and arrangement of the controls, the controls generally perform similar functions and are carefully labeled.

In operation, a beam of electrons generated inside the cathode-ray tube is focused on the fluorescent screen of the tube, which then produces a tiny spot of light where the beam strikes. This beam is then bent or deflected by applying voltage to two sets of electrostatic deflection plates so that the spot of light on the screen moves or "writes," producing a pattern on the screen determined by the voltages applied to the deflection plates. In most instances, a definite "timing" voltage is applied to the horizontal plates so that the beam is swept from left to right uniformly in a definite period of time such as 1/60 sec, and then returned almost instantly to the left side to repeat indefinitely. If at the same time a voltage is applied to the vertical deflecting plates which is of periodic nature with a frequency of, say, 60 cycles, a stationary trace appears on the screen which permits the observer immediately to determine the instantaneous variations of voltage during the cycle. Owing to the ease and speed with which the beam of electrons can be deflected, it is possible to record very rapid variations of voltage that magnet-type oscilloscopes could not follow.

Choice of a Suitable Oscilloscope

Commercial equipments have been built using 1-, 2-, 3-, 5-in., and even larger screen-diameter tubes. The equipments having the larger size tubes obviously give a larger, easier-to-read picture. On the other hand they are larger, heavier, and generally more expensive. Where portability is not necessary, a 5-in. size might well be most desirable; if the equipment must be carried around frequently, the 3- or 2-in. will probably be most satisfactory; even the 1-in. is capable of giving very satisfactory results where extreme portability is necessary.

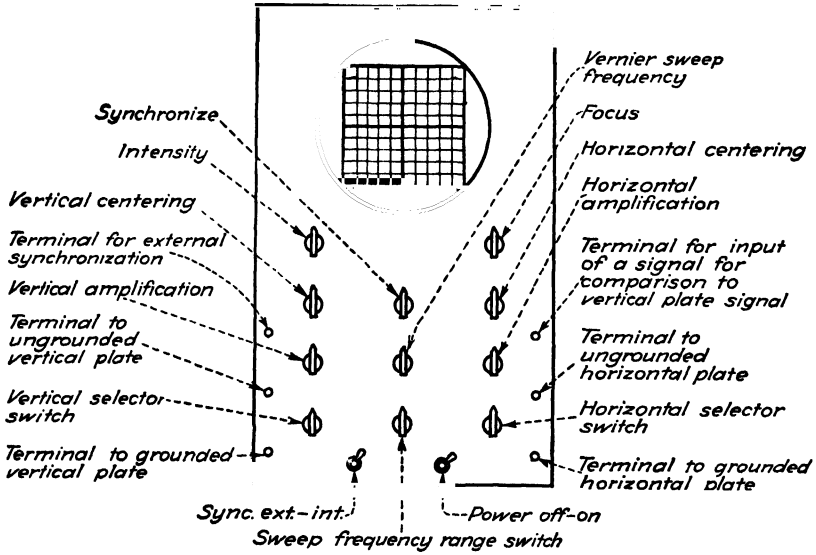

Synchronize
Intensity
Vertical centering
Terminal for external synchronization
Vertical amplification
Terminal to ungrounded vertical plate
Vertical selector switch
Terminal to grounded vertical plate
Vernier sweep frequency
Focus
Horizontal centering
Horizontal amplification
Terminal for input of a signal for comparison to vertical plate signal
Terminal to ungrounded horizontal plate
Horizontal selector switch
Terminal to grounded horizontal plate
Sync. ext-int.
Power off-on
Sweep frequency range switch

FIG. 3-1.

Although there are a few oscilloscopes available which are satisfactory, most of those now on the market that have come to our attention require some modification to make them suitable for industrial use. At least one and generally more modifications must be made. Before purchasing an oscilloscope, obtain an instruction book with the circuit diagram, and make sure that the following modification, described at the end of this chapter, can be made without excessive rebuilding:

1. Direct-current deflection.
2. Sweep synchronization.
3. Input circuit.

Technique in Using the Oscilloscope

So that effective use can be made of an oscilloscope, it is necessary (1) to have a dependable instrument modified as outlined, (2) to be thoroughly familiar with the particular oscilloscope to be used, and (3) to become familiar with the wave shapes of the apparatus to be installed or maintained when this apparatus is functioning properly.

After reading the manufacturer's instruction book, one unfamiliar with oscilloscopes should first familiarize himself with such simple adjustments as beam intensity, focus, and sweep frequency. After a good sharp beam has been obtained and the sweep circuit is causing the spot to move across the screen so as to produce a straight horizontal line pattern, the deflection may be checked. With the amplifier cut out and with short input leads to ensure against pickup, turn the potentiometer for maximum sensitivity and note the position of the zero line on the transparent cross-sectioned screen generally provided in front of the tube screen. In most cases, the modification to permit reading direct current requires the removal of the vertical centering circuit. Thus it will be necessary either to note the position of the true zero to the scale zero or, if it is possible, to move the transparent screen up or down until its zero coincides with the true zero.

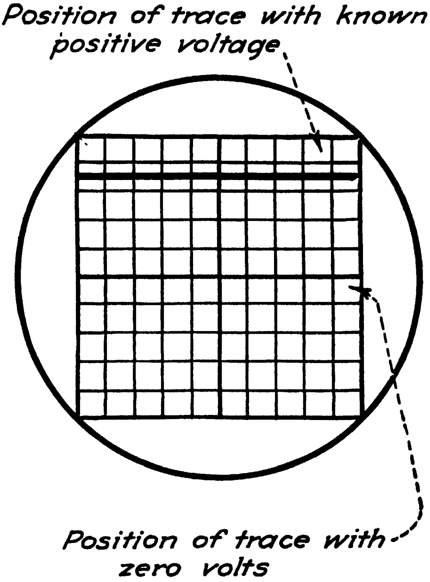
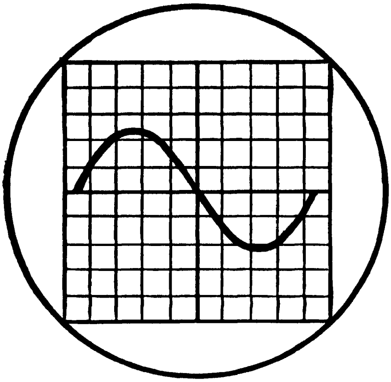

Position of trace with known positive voltage
Position of trace with zero volts

FIG. 3-2.

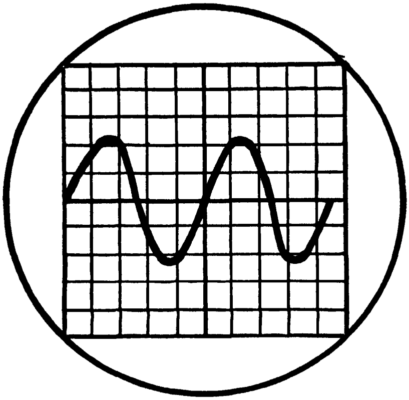
Direct-current Readings

Next a source of direct current, such as a 45-volt *B* battery, should be connected to the input terminals with the positive lead connected to the ungrounded side. If the oscilloscope has been properly modified to read direct current, the horizontal trace should be displaced vertically upward as shown in Fig. 3-2 and should remain in that position as long as the battery voltage is applied. If the instrument has not been properly modified, it may deflect momentarily and then return to zero indicating it cannot read direct current at all, or it may deflect downward indicating reversed sense. Either condition should be corrected as soon as possible.



60 cycle trace with
60 cycle sweep frequency

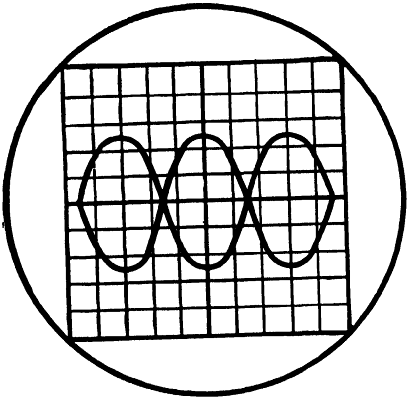
FIG. 3-3.



60 cycle trace with
30 cycle sweep frequency

FIG. 3-4.

At this time it is possible to determine the deflection sensitivity in terms of volts per inch or volts per screen division at full sensitivity. This sensitivity will vary depending on the type of tube used and the anode voltage; higher anode voltages producing brighter patterns but lower deflection sensitivities. Sensitivities ranging from 70 volts per in. to several hundred may be anticipated. It may also be desirable at this time to check the deflection sensitivity at a number of different positions of the sensitivity control potentiometer so that a calibration curve can be made showing volts per division (or inch) against potentiometer setting.

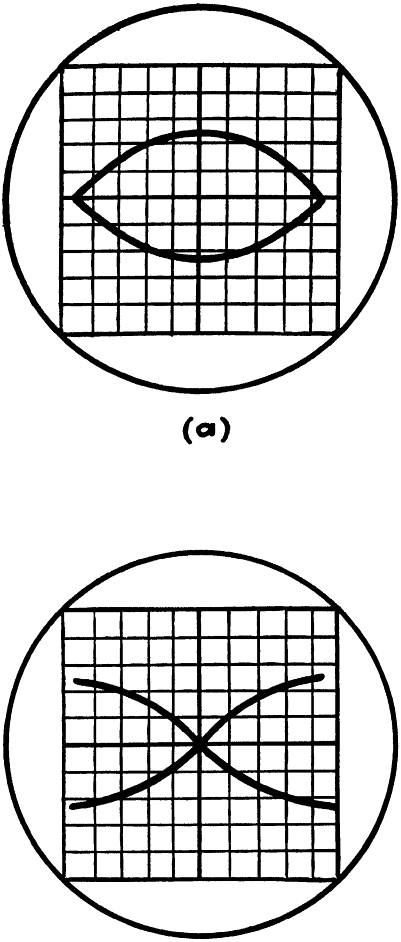


60 cycle trace with
40 cycle sweep frequency

FIG. 3-5.

Alternating-current Readings

It is suggested that a sine-wave voltage of supply frequency next be applied to the deflecting plates to observe the operation of the sweep

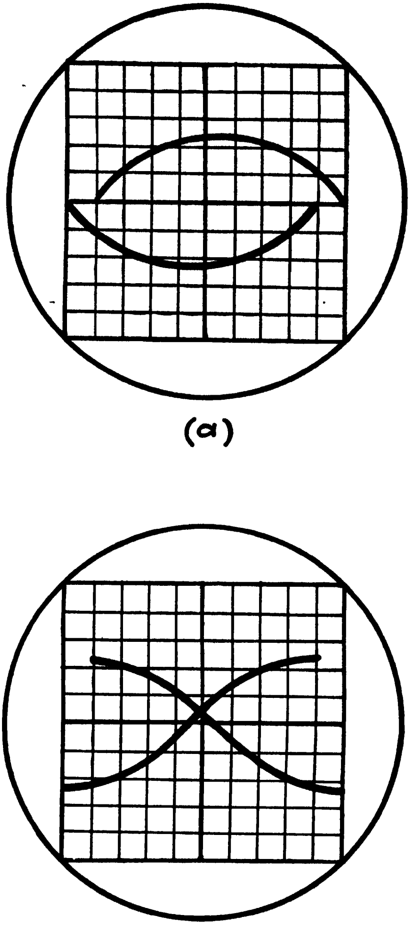


(a)

(b)

60 cycle trace with
120 cycle sweep frequency
(Synchronized at different
parts of cycle)

FIG. 3–6.



(a)

(b)

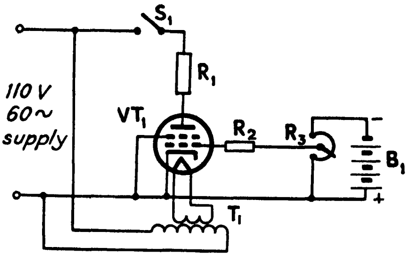
60 cycle trace with
120 cycle sweep freqency
showing distortion due to
excessive synchronization
of signal

FIG. 3–7.

and the synchronizing circuits. The best procedure to follow is to turn the synchronizing control to zero and then adjust the sweep-range switch and the sweep-vernier potentiometer to approximately the right value so that the pattern is almost stationary on the screen. Then with the proper selector switches thrown to obtain the synchronizing signal from the supply frequency, the synchronizing potentiometer should be turned up slightly, and in some cases the vernier sweep slightly readjusted, until the pattern stands still on the screen. Avoid excessive synchronizing voltages to minimize sweep distortion. Figures 3-3 to 3-7 show some of the patterns that may be obtained.

Several Methods of Checking Sweep Sense

Next, check the direction of the sweep to determine if time reads from left to right as it is supposed to do. This may be accomplished in several ways. If the sweep circuit is capable of going down to very low frequencies, such as 5 or 10 cycles per sec, it is possible to see the spot move across the screen and determine whether it is moving in the right direction. If the sweep frequency does not go down low enough to observe this, it is often possible to connect an additional capacitor across the largest capacitor in the sweep circuit and lower the frequency sufficiently to observe the direction. This, of course, will require removing the case temporarily to make the connections.

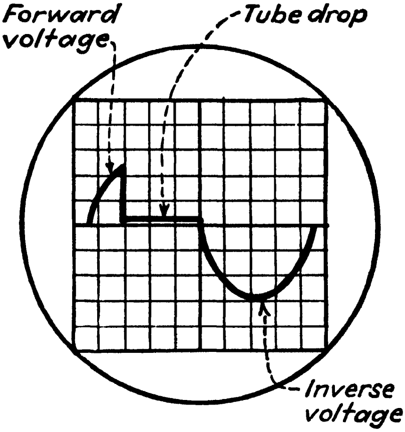


VT1 – 205t Thyratron
R1 – 1,000 ohms 10 watts
R2 – 100,000 ohms 1 watt
R3 – 100,000 ohms 1 watt
B1 – 22.5 volt battery
T1 – 110 V./6.3 V. .6 amp.

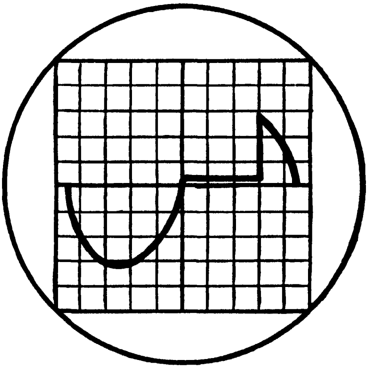
FIG. 3-8.

Another simple method is to look at some known wave shape such as the anode-cathode voltage of a phase-controlled thyratron tube. If a circuit of this sort is not available, a circuit shown in Fig. 3-8 would be suitable for this purpose. Connect the oscilloscope across the anode and cathode of the thyratron *VT*1 with the ground terminal of the oscilloscope on the cathode side of the thyratron. After allowing the thyratron cathode to heat 30 sec, close the anode switch *S*1 and adjust the grid bias with the potentiometer *R*3 until, with the tube turned partly ON, a trace similar to Fig. 3-9*a* or *b* is obtained. If the trace is similar to *a*, the sweep is in the correct left-to-right direction; if it is like *b*, it is incorrect.

Another way to check sweep direction is to look at two different voltages of known phase relationship while holding the sweep in synchronism with one of them. For example, Fig. 3-10*a* shows a simple circuit composed of a resistor and a capacitor of approximately equal impedance (say 25,000 ohms and 0.1 μf for 60 cycles) so that we know that the capacitor voltage measured from points 2 to 3 will be approximately 70 per cent of the supply voltage measured from 1 to 3 and lagging it by about 45 deg. Thus, if we connect the ground terminal of the oscilloscope to point 3 and connect the high side first to point 1 and then to point 2, the peak of the second sine wave should be lower and to the right of the first wave, as shown in Fig. 3-10*b*, when the sweep is from left to right. If the second and smaller sine wave appears to "lead" the first, the sweep is backward.



Correct Sweep Sense
(a)



Incorrect Sweep Sense
(b)

FIG. 3–9.

In attempting to note the relative position of two simple sine waves, it is generally possible to remember the position of the first on the screen until the second trace is observed and their relative phase relations noted. However, when two, or even more, complex waves are to be successively viewed on the screen, and a knowledge of their relative phasing and magnitudes is necessary, some form of recording is helpful. On large tubes such as the 5-in. size, one scheme used has been to use a soft grease pencil to sketch the successive traces directly on the end of the tube. This scheme is not practicable on a small tube, and even on a large tube some difficulty may result if there are many traces.

Another scheme frequently used is to place a thin piece of tracing paper over the end of the tube and sketch the trace directly on the paper. This has the advantage of providing a permanent record. Care must be taken to fasten the paper to the oscilloscope screen in such a way that it cannot move between successive traces, or some indexing scheme must be used. A disadvantage of this system is that the paper cuts down the intensity of the trace, and it is sometimes necessary to remove it to see transient phenomena or any very quick voltage change that produces a faint trace.

A third method is simply to sketch the observed trace on cross-section paper that has cross-section lines similar to the screen on the face of the oscilloscope. With a little practice this is probably just as quick as the other methods and eliminates most of their disadvantages. It has an additional advantage from the standpoint of safety since there is no necessity of touching the case of the instrument, thus minimizing the shock hazard when the case is "high" to ground.

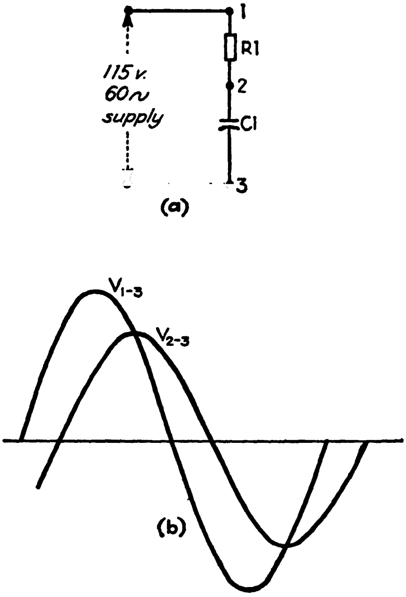


Fig. 3-10.

Precautions in Using Oscilloscope

Several precautions pertaining both to personal safety and to satisfactory results should be carefully observed in the use of the cathode-ray oscilloscope on industrial apparatus.

1. Remember that the lower input terminal is tied to the chassis of the oscilloscope. If possible, try to connect this plate at or near ground potential on the circuit being examined, to minimize the danger of shock from the instrument case. Unless the oscilloscope has been specially insulated, do not connect this chassis side to a potential higher than 550 volts to ground or you may puncture the oscilloscope supply transformer and perhaps cause considerable damage, particularly when high-current-capacity circuits are being checked.

If the chassis is at any potential other than ground, care must be taken not to allow the case to short to ground. Most metal-case oscilloscopes have rubber bumpers on the bottom that prevent marring a finished surface and also serve to insulate the case if it is set on a metal surface. However, as the bumpers sometimes come off, it is generally safer to set the instrument on a dry board or other insulating surface whenever possible. Care should be taken in making any adjustments on the oscilloscope under these conditions, since a shock may result if the operator comes in contact with any of the metal parts connected with the case, unless he is insulated from ground.

2. Since the deflecting plate connected with the chassis has considerable capacity and possibly some leakage to ground, this plate should not be connected to high-impedance points in the circuit under test such as vacuum-tube grids fed through large grid resistors. If this

caution is not observed, the additional capacity and leakage may affect the circuit being observed so that any observations are worthless.

3. Care should be taken to avoid spurious pickup which may distort the observation. In dealing with low-impedance circuits near power apparatus, the chief source of trouble may be from magnetic fields. This is particularly true, for example, in working near large resistance-welding machines. To check this condition, connect the "high" side of the oscilloscope to the same terminal to which the "low" side or chassis is connected. Under this condition, there should be only a straight-line zero trace. If, for any reason, any other deflection takes place, the oscilloscope should be moved and turned until the deflection disappears, and the trace remains at zero when any machine in the vicinity is operated. It should be noted that it is not always necessary to move completely out of a weak magnetic field. If the oscilloscope is rotated and inclined until the stray magnetic field is essentially axial, its effect on the beam will probably be negligible.

In the case of very high-impedance circuits, such as photoelectric circuits, the capacity of the connection of the "high" deflection plate and the deflection plate itself, to both the "low" side and to other objects, such as ground, may cause the circuit to function improperly. In such cases, the leads should be made as short as possible and it may be desirable to shield the high-side lead.

Oscilloscope Modification

Direct-current Deflection

Most of the oscilloscopes now on the market give only a momentary deflection when a d-c voltage is applied to the input terminals. This characteristic, which is objectionable for most industrial uses, can sometimes be overcome by applying the signal directly to the vertical deflecting plates (a suitable external voltage divider must be used if the voltage is too large) where these terminals are available. However, it is generally preferable to change the internal connections so that it is not necessary to carry around an additional external voltage divider "haywired" to the oscilloscope. If this modification is properly made, it still permits switching in the a-c amplifier, generally available for very low-voltage signals, although under this condition it is not possible to observe d-c signals.

In making this modification, the polarity of the vertical deflection and the direction of the sweep should be corrected if necessary so that when the oscilloscope is connected to read direct current, a positive signal on the ungrounded vertical deflection plate causes the beam to move upward, and the sweep "writes" from left to right.

FIG. 3 11. Electronic control panel being checked with cathode-ray oscilloscope, a most useful instrument for checking wave shapes and displacements when searching for faults.

Sweep Synchronization

Some instruments are designed so that it is difficult or impossible to synchronize the sweep when the amplifier is not used. It is generally possible to correct this by feeding back some of the supply frequency through a suitable ON-OFF or selector switch to the synchronizing transformer generally used in the grid circuit of the sweep-circuit thyratron tube.

Input Circuit

If the instrument is to be used on high-power circuits, it is generally desirable to modify the input circuits. Terminals with more creepage and wider spacing, preferably mounted on an insulated panel, reduce the danger of short circuit due to carelessly attached leads. A series protective resistor of about 10,000 ohms mounted directly on the ungrounded deflection terminal and backed up with a small fuse minimizes possibility of trouble if the input potentiometer fails. It is also generally desirable to replace the original input potentiometer with one having about 5 megohms resistance to minimize loading of any high-impedance circuit being measured. This potentiometer is generally fitted with a switch so that when it is turned for maximum sensitivity the potentiometer circuit is opened, giving a minimum loading effect on the circuit being observed.

CHAPTER 4

INSTALLING, MAINTAINING, AND SERVICING ELECTRONIC RELAYS AND TIMING RELAYS

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Electronic relays and electronic timing relays are important members of the rapidly growing family of industrial electronic control devices. As their applications become more widespread, general information concerning their installation, maintenance, and servicing becomes increasingly important.

Electronic Relays

Whereas the term "electronic timing relays" instantly gives one a definite idea regarding the nature of such devices, the term "electronic relays" is not so specific. Strictly speaking, electronic relays would include a large variety of electronic devices, such as photoelectric relays, electronic timing relays, and electronic contact amplifiers. In this chapter, the term will apply only to those devices, whose function it is to open and/or close *control circuits for other electrical devices* in response to the opening or closing of a circuit which by itself is not capable of handling the current required to operate those electrical devices.

Many applications of electronic relays have been made, and their field of application is certain to increase in the future. One typical application is an electrical instrument, such as a voltmeter or ammeter, provided with a very small contact on its pointer. This contact is connected to an electronic relay, which controls some electrical device requiring more power than the small contact can handle. The electronic relay used in this application may be called an "electronic contact amplifier."

In another application, the rise or fall of a semiconducting liquid, such as water in a pipe or tank, can be detected by locating, at a desired position, electrodes or probes that are connected to an electronic relay whose contacts are used to control the desired electrical devices.

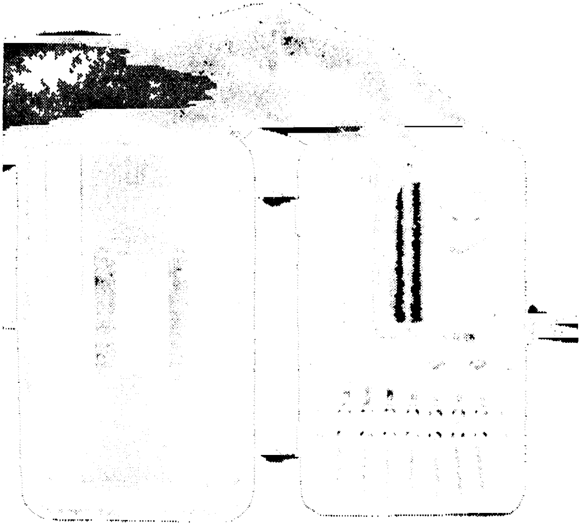

FIG 4–1*A* Telephone-type magnetic relay on an electronic relay being operated manually to check proper functioning of the contacts.

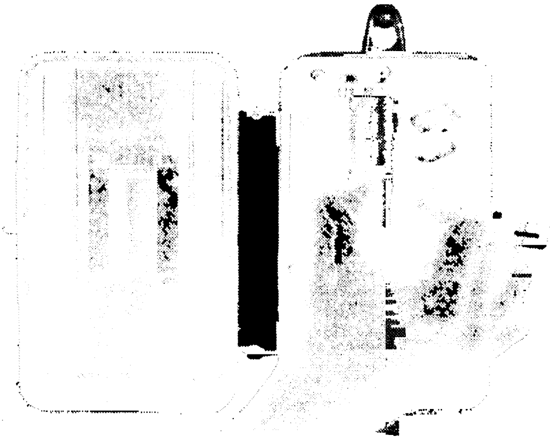

FIG 4–1*B* Adjustment of armature stops or contacts to compensate for wear is sometimes necessary to maintain satisfactory operation.

Mechanical Considerations

It is obvious that all electrical devices should be adequately protected from accidental damage prior to and during their installation. This is especially true for electronic relays and, as a matter of fact, for all electronic devices, because parts used in them can be easily damaged beyond repair unless the devices are properly cared for. Dirt, oil, grease, excessive moisture, corrosive atmosphere, and extreme temperatures are particularly harmful to electronic devices not suitably protected. The careful storing and handling of them are vital factors for all installations.

Electronic devices are often supplied with the tubes in their respective sockets. Care should be exercised during the installation of such equipment so as not to damage the tubes.

Planning Installations

Planning the installation of electronic relays is also important. Although the wiring diagrams and instruction books furnished with the devices supply much of the detailed information regarding them, it is usually necessary to study thoroughly all conditions from the viewpoint of each particular installation.

One of the first factors to be considered is the permanent location of the electronic relay and its associated devices. *Locate these as close together as practicable so that the wiring between them will be short. Avoid placing the devices where they will be subjected either to excessive vibration or to other harmful conditions such as those already mentioned.*

The leads of the electronic relay can be thought of as control and power leads. The control leads are wires from the initiating device, such as the small contact on a voltmeter or an ammeter, or electrodes in a pipe or tank. The power leads are the wires from the power supply and from the electrical devices to be controlled by the electronic relay. Control connections *should always be kept separated* from power connections to make sure that transient voltages in the power circuits will not be induced in the control circuits.

One way of making certain that there will be no interaction between the power circuits and the control circuits is to place them in separate metal conduits or suitable metal enclosures. The conduits should be connected to the enclosing case of the electronic relay and solidly grounded. In addition, for some types of electronic relays, special shielded wires may be required. Recommendations regarding the maximum allowable length of control connections and the type of shielded wire (if any) to be used can be found in the instruction book or obtained from the electronic relay manufacturer.

After the installation has been completed, refer to the instructions supplied with the electronic relay and follow the procedure given for putting the equipment into operation.

Inspection

These electronic devices should not require a great deal of maintenance because usually the only moving parts subject to mechanical wear are the relays mounted in the device. Other elements, such as resistors, capacitors, tubes, and transformers do not wear out. Although these latter elements are usually conservatively rated, there may be an occasional failure.

In those installations where failure of the electronic device and the resultant stoppage of production would be serious, a spare device and a spare set of tubes should be kept on hand.

Although the life of tubes should be several years, all tubes do not have the same life. In those instances where a tube failure at an inopportune time would be serious, it is advisable to test the tubes periodically so that a tube that is nearing the end of its useful life can be detected and replaced. Radio-type tubes can usually be tested at a radio store. However, if an installation has a large number of tubes (perhaps 50 or more) in use, it may be more economical to have a suitable tube tester available in the maintenance shop. Keeping accurate records provides the experience data necessary to future maintenance procedures and scheduling. And more important, they will indicate the stock requirements necessary for successful maintenance operation.

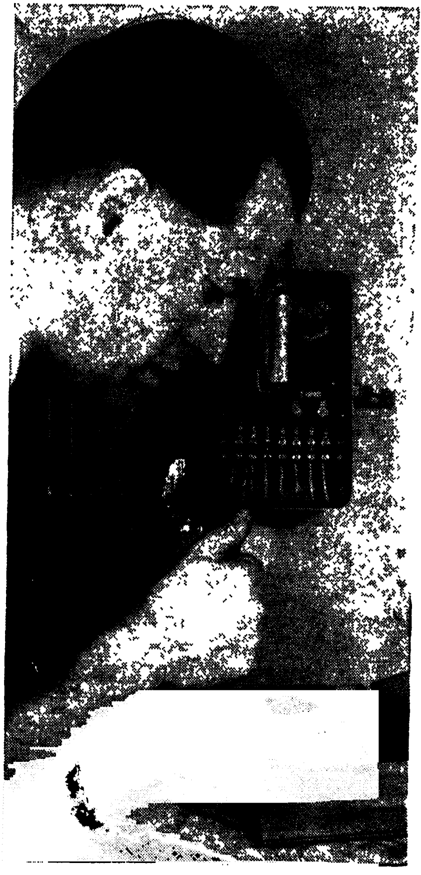

FIG. 4–2. Electronic relay being checked for line voltage, which should correspond to within a variation of plus or minus 5 per cent of nameplate rating.

All devices should be kept clean and free from dirt and moisture. *Do not use oil on any of the parts.* If contacts or other moving parts show excessive wear, readjust or replace them. A guide for periodic inspection is given in Table I.

Trouble Shooting

If a piece of equipment has been operating satisfactorily and then stops for no apparent reason, a preliminary servicing may reveal the cause of the trouble. A suggested procedure follows:

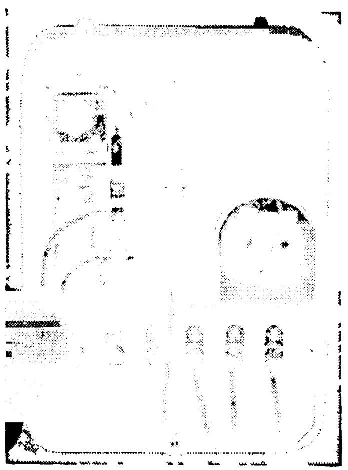

FIG. 4-3. Terminal binding screws on an electronic timing relay being tightened during installation. Care should be exercised not to damage the device by using an oversize screw driver or by exerting too much force.

1. Check the power supply to the equipment.
2. Check all fuses.
3. Carefully inspect all equipment other than the electronic devices.
4. Examine all connections.
5. Inspect the electronic devices.
    a. Examine the contacts on the relay to determine if they open and close properly when the relay is operated by hand. (See Fig. 4-1*A*.) Frequently, a slight adjustment of either the armature stops or the contacts, to compensate for contact wear, is all that is required.
    b. Replace the tubes, one by one, to determine whether a tube has failed. Check the operation of the equipment each time a tube is replaced.

Experience has shown that this procedure will take care of most failures, but if the preliminary servicing does not reveal the cause of the trouble, it is necessary to search further. More detailed servicing instructions are given in Table II.

Electronic Timing Relays

The usual electronic timing device is provided with a magnetic relay that is energized or deenergized a definite time after an external initiating switch has been operated. The response of the relay to the operation of the initiating switch depends upon the circuit employed in the electronic timing device. For this reason, it is possible to build electronic timing relays to meet the requirements of a wide range of applications. Another advantage of this device is its few moving parts. Parts that can wear out are at a minimum because the timing operation depends upon the electrical conditions of stationary circuit elements.

Electronic timing relays are supplied either as parts of a panel on which other devices are mounted, wired, and tested at the factory, or as unit devices to be installed and interconnected by the user with other devices to make a complete equipment. The installation of a factory-built panel is usually straightforward because it is only necessary to make connections to the terminal boards on the panel in accordance with the wiring diagram. *If the initiating contacts for the timers and the time-adjusting potentiometers are not on the panel, control leads to these parts should be kept separate from power leads.*

The precautions to be observed in the installation of unit-type electronic timing relays are similar to those already mentioned for electronic relays except that shielded wires for control connection usually are not required; *nevertheless, control and power connections must be kept separated.*

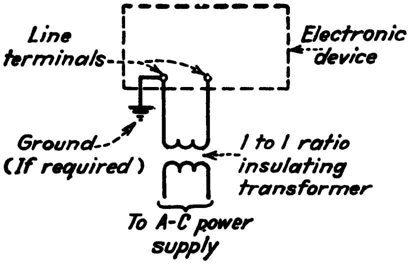

FIG. 4-4. Use of a 1 to 1 ratio insulating transformer to enable line terminal of electronic device to be grounded (if required) when a-c power supply is not suitably grounded.

One question invariably arises in the application of electronic timing relays: Can a single initiating contact serve the two purposes of initiating the timer and energizing a load such as the coil of a relay, contactor, or solenoid? Although many successful applications of this type have been made, there have been several that have been unsatisfactory. In these cases, inconsistent timing was caused by the bouncing of the initiating contact when it closed; the transient voltage, which appeared across the initiating contact because of the momentary interruption of the load current, was being impressed in the grid circuit of the electronic timing relay. In most cases, the trouble was corrected by using two contacts: one for initiating the timer and one for energizing the load. As a result of these experiences, it is recommended that separate contacts be used when a timer is to be initiated at the same time that a load is to be energized. A single contact may be used if actual tests on completed equipment prove that satisfactory operation is obtained.

Trouble Shooting

The procedure for servicing electronic timing relays is also similar to that for servicing electronic relays. If this servicing does not locate the defect, follow the suggestions outlined in Part I of Table III

Sometimes, it is difficult to determine whether or not the electronic *timing relay itself is operating. This can be checked by disconnecting* the wires to the initiating contacts and using a separate initiating switch connected directly to the terminals on the timer. Operate this switch in the usual manner and observe the operation of the time relay and compare the time delay with the calibrated values. (See Fig. 4-8).

It may be of help to observe changes of magnetic-relay coil voltages during a timing cycle. This can be done most readily by connecting to the coil of the magnetic relay a high-resistance d-c voltmeter or multimeter. In some forms of electronic timing relays when the potentiometer is set for maximum time delay, the relay voltage will be zero for about 80 per cent of the time after the initiating switch is closed. The voltage then gradually rises, and at a certain value the magnetic relay should pick up. In another type of timing relay, the coil voltage is maximum, and the relay energized before the initiating switch is closed. As soon as the initiating switch is closed, the voltage becomes zero and remains zero for about 80 per cent of the time and then gradually rises.

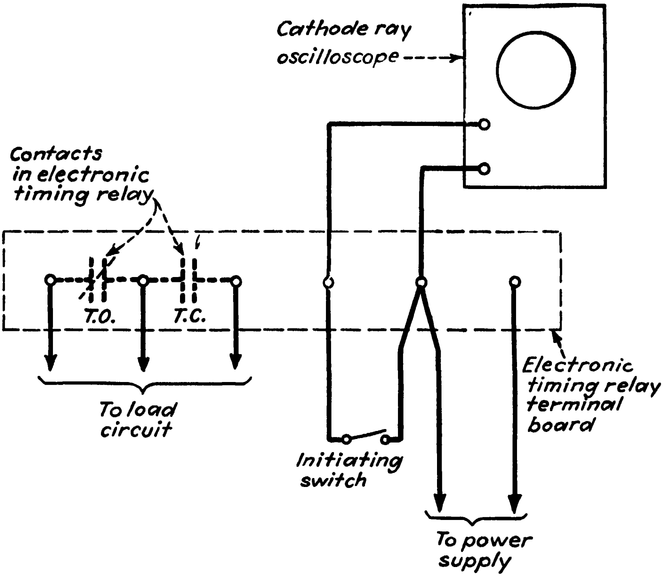

FIG. 4-5. Use of cathode-ray oscilloscope to check presence of transient or undesirable voltage in wires from an electronic timing relay to initiating switch.

In general, the voltage rises near the end of the time-delay period in an electronic timing relay using *vacuum tubes.* If the timing relay uses a *thyratron tube,* the voltage will change abruptly at the end of the time-delay period.

Troubles Due to Factors outside the Timing Relay

Troubles due to factors outside the electronic timing relay are usually of two kinds: recycling and inconsistent timing. Where such troubles occur, it is usually possible to trace their cause to transient voltages that affect the operation of the time relay.

Where trouble of this kind is encountered, it is difficult and sometimes impossible to watch the operation of the time relay and to determine when the most effective curative measure has been applied.

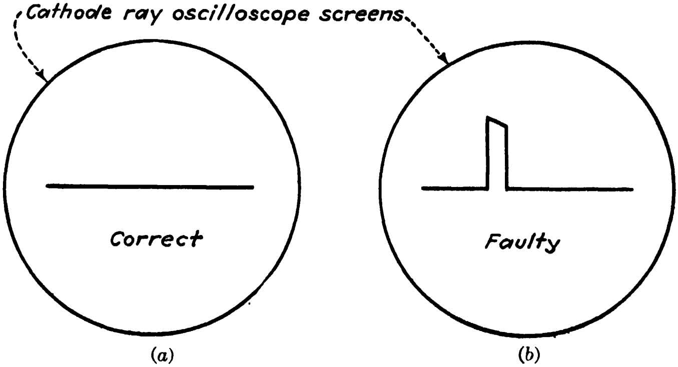

FIG. 4–6. Trace (*a*) indicates initiating switch remains closed and no transient voltages are present in circuit to initiating switch. Trace (*b*) indicates either the initiating switch has bounced open momentarily or transient voltages are present in circuit to initiating switch.

The reason for this is that the source of transient voltages, their magnitude, and the way in which they are being impressed on the time relay vary greatly with each installation.

The use of a cathode-ray oscilloscope may be helpful in determining how such transients are getting into the electronic-timing-relay circuit. Connect the oscilloscope to the terminals on the relay to which the initiating switch or contacts connect (see Fig. 4-5). When the initiating contacts close, the trace seen on the oscilloscope screen should immediately take a position corresponding to zero voltage and remain at zero for as long as the initiating switch is closed. Such a trace is shown in Fig. 4-6*A*. If the trace does not remain at zero as in Fig. 4-6*B*, it indicates that transient or other undesirable voltages are being introduced into the electronic-timing-relay circuit and steps must be taken to eliminate this voltage or to reduce it to a minimum.

The remedies suggested in Tables II and III are those which have been found to work in the majority of cases. Frequently, it may be necessary to try others. One method of attack is to study the wiring arrangement of the devices connected to the time relay, and to decide which ones are the sources of the transient voltages. There are then two ways to prevent these transient voltages from affecting the time relay:

1. Suppress the transient voltage at the source, or
2. By-pass the transient voltage around the time relay.

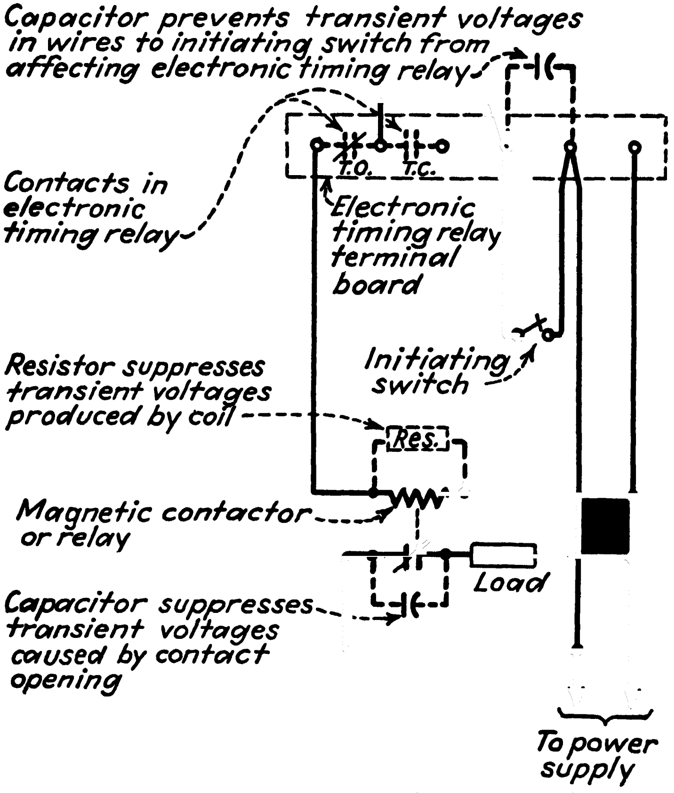
Capacitor prevents transient voltages in wires to initiating switch from affecting electronic timing relay
Contacts in electronic timing relay
T.O.
T.C.
Electronic timing relay terminal board
Initiating switch
Resistor suppresses transient voltages produced by coil
Res.
Magnetic contactor or relay
Load
Capacitor suppresses transient voltages caused by contact opening
To power supply

FIG. 4-7. Some typical methods of correcting trouble due to transient voltages. (See "Trouble-shooting chart—Electronic Timing Relays," Parts II and III.)

Relay and contactor coils are frequently sources of transient voltages which can be suppressed by resistors connected in parallel with the coils. [Typical values of resistors are 400 ohms (35 watts) on 115 volts, or 1,000 ohms (50 watts) on 230 volts.]

The transient voltages may appear across closed contacts when they open, or across open contacts that bounce on closing. A small capacitor (typical values: 0.05 or 0.1 μf) connected across these contacts, as in Fig. 4-7, is frequently a sufficient remedy.

If the number of these devices is large, it may be uneconomical to add these corrective measures to each. Consideration should then be given to by-passing the transient at the terminals on the time relay. This may be done, sometimes, by connecting a capacitor (typical values: 0.05, or 0.1 μf) to the initiating terminals on the time relay, as shown in Fig. 4-7.

Recycling

Part II of Table III suggests remedies for trouble under "Timing relay recycles—magnetic relay alternately picks up and drops out." This recycling usually occurs after the timing relay has timed out and the initiating contact is still in the timing position.

When trouble of this kind is being serviced, it is desirable to have some method of determining when the most effective remedy has been applied. One way is to connect a d-c voltmeter to the coil of the magnetic relay and to observe the changes in voltage whenever recycling occurs. When the timing relay recycles or tends to recycle, the voltage will dip, sometimes a little and sometimes to zero. When complete correction has been applied, the voltage should not dip.

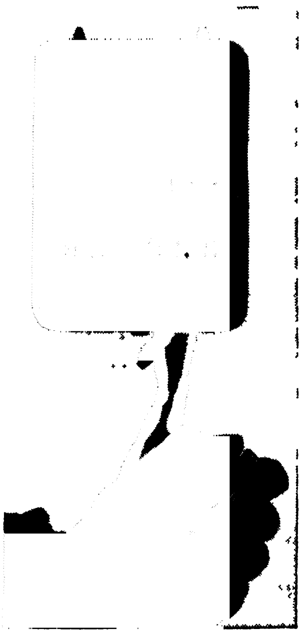

FIG. 4-8. Electronic timing relay being operated with a separate initiating switch. Time delay being checked by stop watch.

Inconsistent Timing

There may be devices in the installation, other than the electronic timing relays, which are not consistent in operation and which may be the cause of the inconsistent timing. It is suggested that a study be made of the entire installation to determine what is responsible for the poor results. If the analysis of the equipment shows that a device other than the timing relay is at fault, steps should be taken to correct the condition and assure proper operation.

If it is believed that the timing relay is at fault, attention should be turned to it. The most satisfactory method of determining errors in timing is by use of an automatic time-measure device, such as

1. A stop watch for time delays over 15 sec.
2. A synchronous timer with electrically operated clutch mechanism for time delays over 0.5 sec.
3. A cycle counter for time delays from 0 to 1 sec.

Check the timing for several operations and note any variations. Apply corrective measures, some of which are listed in Part III of Table III, and again note the variations in timing. Select the remedy that yields the best correction.

Shooting Trouble on Electronic Timing Relay after It Has Been Removed from Service

In order to illustrate the location of defective circuit components or wiring, assume that a timing relay using the circuit in the accompanying diagram has failed in service. Also assume that new tubes and a careful inspection of the installation did not correct the trouble and that the device has been removed to the service department.

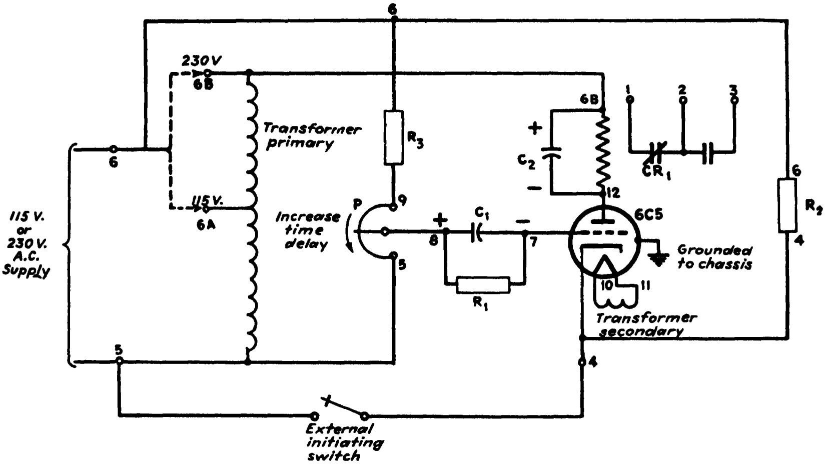

FIG. 4-9. Typical electronic-timing-relay circuit.

Above is a typical electronic-timing-relay circuit in which the circuit components should be as follows for a timing range of 3 to 60 sec.:

$C1$ = 2-μf capacitor.

$C2$ = 6-μf capacitor (electrolytic type).

$CR1$ = Relay whose coil resistance = 6,500 ohms.

P = 10,000-ohm potentiometer.

$R1$ = 10-megohm resistor.

$R2$ = 10,000-ohm resistor.

$R3$ = 12,500-ohm resistor.

Transformer primary rated 115/230 volt.

Transformer secondary rated 6 volts.

The operation of this circuit has been described in Chap. 1.

Shooting trouble on an electronic device should proceed in a systematic manner as follows:

1. Check the operation of the device in the service department.
2. Measure the transformer secondary voltage with an a-c voltmeter (about 6 volts).
3. Remove the timing relay from its case and carefully examine visually all parts. This visual examination is very important because frequently a failure of insulation, circuit component, or wiring will have left some telltale trace which indicates the location of the fault.
4. Check resistances with suitable ohmmeter as follows:
    - *a.* Remove connection from 6 to 6*B* (or 6*A*).
    - *b.* *R*3—Measure resistance of *R*3 (should be 12,500 ohms).
    - *c.* (1) *P*—Measure resistance of *P* (5 to 9) (should be 10,000 ohms).
        - (2) Connect ohmmeter from 8 to 9 and gradually turn shaft of *P* from 9 to 5. Resistance should gradually increase from zero to 10,000 ohms.
        - (3) Connect ohmmeter from 5 to 8 and gradually turn shaft of *P* from 5 to 9. Resistance should gradually increase from zero to 10,000 ohms.
    - *d.* *R*2—Measure resistance of *R*2 (should be 10,000 ohms).
    - *e.* *CR*1—Connect ohmmeter from 6*B* to 12 to measure resistance of *CR*1 coil (should be 6,500 ohms). NOTE: If *C*2 is electrolytic type, disconnect one wire from capacitor before measuring coil resistance.
    - *f.* *R*1—Connect ohmmeter from 7 to 8 to measure resistance of *R*1 (should be 10 megohms). NOTE: Ohmmeter should be set on 50-megohm scale at least. If resistance is low, *C*1 may be shorted. Disconnect one wire from resistor *R*1 and measure resistance of *R*1 again.
    - *g.* Connect ohmmeter (or preferably a 500-volt Megger) from various terminals to chassis or panel to determine if any components or wiring have failed by grounding. If certain parts of the circuit are intentionally grounded, these wires should be disconnected from chassis or panel while making this test. If a ground is still present, parts should be disconnected one by one until the faulty component or wiring is located.
5. Check capacitors for shorts with a suitable ohmmeter or measure their capacitance with a capacitance meter. NOTE: Capacitors that fail usually do so by becoming shorted; however, electrolytic capacitors may fail by becoming open-circuited.
    - *a.* *C*1—Disconnect one wire to resistor *R*1. Connect ohmmeter to *C*1. Resistance should be 100 megohms or higher.

b. *C*2—Disconnect one wire from capacitor *C*2. Connect ohmmeter to *C*2. Resistance should be 100 megohms or higher. If *C*2 is electrolytic type, measure capacitance with capacitance meter. NOTE: If relay *CR*1 chatters and fails to pick up during operation, capacitor *C*2 has probably failed by open-circuiting.

TABLE I.—INSPECTION SCHEDULE

ELECTRONIC RELAYS AND ELECTRONIC TIMING RELAYS

Frequency	What to inspect	What to inspect for
Every 3,000 hr.	Electronic tubes.	In order to maintain continuity of service, all electronic tubes should be tested and replaced if necessary.
1 to 3 months, depending on frequency of operation.	Contacts of magnetic relay.	Excessive wear, burning, or pitting. Replace contacts, if necessary. Amount of wipe on normally closed contacts of sensitive relays. Adjust armature stop to obtain about 1/16 in. clearance between armature arm and spring.
1 to 6 months.	Electronic relays, probes, electrodes, and initiating devices used with electronic relays. Electronic timing relays, auxiliary electrical devices. Wiring.	Presence of dirt, metallic dust, and other foreign material. Because of the high impedance of most electronic circuits, such accumulations may cause trouble. The presence of moisture will make conditions much worse. Particular attention should be paid to probes and electrodes used with electronic relays. Leakage resistance of wiring, cables, and panel surfaces should be in excess of several hundred megohms.
3 to 6 months.	Connections to terminals and plug connections.	Under conditions of vibration, these connections may come loose. Tighten securely.
3 to 6 months.	Auxiliary electrical devices.	Contact wear, loose parts, etc.

TABLE II.—TROUBLE-SHOOTING CHART

ELECTRONIC RELAYS

Trouble	Cause	Remedy
Magnetic relay in electronic devices does not operate on signal from initiating device.	Line voltage not within limits specified.	Correct line voltage.
	Defective tubes.	Check tubes, or if unable to do so, try new ones.
	Positioning key in center of tube base (radio-type tubes) may be broken and tube has been placed in the socket incorrectly.	Replace tube. If another tube is not available, check mating of tube pins with proper socket holes before replacing in socket.
	Excessive leakage in initiating device (probes, electrodes, or contact) or wiring associated with initiating device—caused by moisture accumulation or poor insulation.	Check leakage resistance of initiating device, associated wiring. Disconnect wires to initiating device from terminals on panel and measure resistance between those wires with an electronic voltmeter-ohmmeter. Total leakage resistance should be well in excess of that for which the electronic relay is adjusted.
	Capacitance of wiring from electronic device to initiating device too high.	Use shorter wires. Install shielded cable according to recommendations of electronic device manufacturer.
	Contact-type initiating control doesn't operate.	Repair or replace initiating contact.
	Open magnetic relay coil.	Replace coil or install complete new relay.
	Defective circuit components, such as resistors or capacitors.	If circuit voltages have been included with instructions, check these voltages with a multimeter, as a means of locating the trouble. Otherwise make a visual inspection of the device for defective parts. Check resistance of resistors and coils with an electronic voltmeter-ohmmeter. The resistance of resistors should be within 10 per cent of the rated value. Check capacitors, other than electrolytic types with ohmmeter. Defective capacitors will show practically zero resistance. Check

TABLE II.—TROUBLE-SHOOTING CHART (*Continued*)
ELECTRONIC RELAYS

Trouble	Cause	Remedy
		electrolytic capacitors with capacitance meter. Because of limited life, failure may occur after several years. When replacing, observe polarity.
Contacts on telephone-type magnetic relay either stick or do not make good contact.	Insufficient wipe or normally closed contacts.	Bend armature stop to obtain about 1/16 in. clearance between armature and contact spring.
	Contacts worn badly.	Replace contacts or entire relay.
Electronic relay operates erratically.	Variations in line voltage outside the limits specified for the device.	If possible, use a better regulated power supply, such as is ordinarily used for lighting circuits. Otherwise, install a constant-voltage transformer if electronic relay is designed for alternating-current.
Magnetic relay on the electronic device opens and closes at a rapid rate.	Grounded side of power supply on wrong terminal of electronic relay.	Grounded side of power supply must be connected to terminal as specified in the instructions. If device operates from alternating-current and power supply cannot be grounded, a 1:1 ratio transformer should be installed and the proper terminal of the relay grounded. (See Fig. 4-4.)
	Capacitor that is connected in parallel with the relay coil may be open.	Replace capacitor.

TABLE III—PART 1.—TROUBLE-SHOOTING CHART
ELECTRONIC TIMING RELAYS

Trouble	Cause	Remedy
Magnetic relay does not operate at end of time delay after initiating contact has been operated.	Line voltage not within limits specified.	Correct voltage to within rated limits.
	Proper tap on electronic timing relay corresponding to line voltage may not have been used.	Select and make proper tap connection.

TABLE III—PART 1 (*Continued*).—TROUBLE-SHOOTING CHART
ELECTRONIC TIMING RELAYS

Trouble	Cause	Remedy
	Positioning key in center of tube base (radio-type tubes) may be broken and tube has been placed in socket incorrectly.	Replace tube. If another tube is not available, check mating of tube pins with proper socket holes before replacing in socket.
	Initiating contact does not function.	Repair or replace initiating contact.
	Open magnetic relay coil.	Replace coil or install complete new relay.
	Wires touching each other or panel wires loose — soldered connections broken. Parts normally insulated from panel or from each other grounded or touching.	Locate fault and repair.
	Defective circuit components, such as resistors or capacitors.	If circuit voltages have been included with instructions, check these voltages with a multimeter as a means of locating trouble. Otherwise, make a visual inspection of the device for defective parts. Check resistance of resistors and coils with an electronic voltmeter-ohmmeter. The resistance of resistors should be within 10 per cent of the rated value. Check capacitors, other than electrolytic types, with ohmmeter. Defective capacitors will show practically zero resistance. Check electrolytic capacitors with capacitance meter. Particular attention should be given to electrolytic capacitors, since this type of capacitor has a limited life and failure may occur after several years of operation. When replacing, be sure to observe polarity.

TABLE III—PART 1 (*Continued*).—TROUBLE-SHOOTING CHART

ELECTRONIC TIMING RELAYS

Trouble	Cause	Remedy
Magnetic relay on the electronic timing relay opens and closes at rapid rate.	*Capacitor that is connected in parallel with relay coil may be open.*	*Replace capacitor.*
Contacts on telephone-type magnetic relay either stick or do not make good contact.	Insufficient wipe of normally closed contacts.	Adjust armature stop to obtain about 1/16 in. clearance between armature and contact spring.
	Contacts worn badly.	Replace relay.
Time delay not smoothly adjustable by the potentiometer or rheostat.	Potentiometer or rheostat has failed.	Replace defective part.
Time delay always minimum.	Potentiometer open on "maximum" end.	Replace potentiometer.
	Defective tube.	Replace tube.
	Timing capacitor shorted or open-circuited.	Replace capacitor.
	Defective resistors, capacitors, etc.	Locate defective part and replace. Resistors and capacitors (except electrolytic types) may be checked with electronic voltmeter-ohmmeter. Resistance of resistors should be within 10 per cent of their rated value. Defective capacitors will show practically zero resistance. Check electrolytic capacitors with capacitance meter.
Time delay always maximum.	Potentiometer open on "minimum" end.	Replace potentiometer.
	Defective resistors, capacitors, etc.	Locate defective part as above and replace.

TABLE III—PART 2.—TROUBLE-SHOOTING CHART

ELECTRONIC TIMING RELAYS

Trouble due to factors outside the electronic timing relay. Most troubles outside the timing relay are due to transient voltages that affect the operation of the timing relay. See text.

Trouble	*Cause*	*Remedy*
Timing relay recycles—magnetic relay alternately picks up and drops out. (See text under "Recycling.")	Excessive line-voltage regulation.	If possible, use a better regulated power supply; or Install a constant-voltage transformer; or Use an auxiliary magnetic relay that picks up and seals in and closes load circuit when magnetic relay on timing device picks up; or Use form of electronic timing relay not affected by the line-voltage regulation.
	Initiating contact bounces open, owing to vibration of devices on which initiating contact is mounted.	Arrange initiating contact so it will not bounce open; or Use an auxiliary magnetic relay with coil controlled by initiating contacts and with contacts on relay used to initiating timing relay.
	The normally open contacts of the magnetic relay connected to a load which, when energized, induces a transient voltage in the external wiring.	Connect a resistor across the load with shortest possible wires. (Typical values: 400 ohms on 115 volts, 1,000 ohms on 230 volts.) or Connect a capacitor* across terminals on timer which connect to initiating contact.
	The normally closed contacts of magnetic relay connected to a load which, when deenergized, induces a transient voltage in the external wiring.	Connect a capacitor* across normally closed contacts (see Fig. 4-7); or Connect a capacitor* across terminals on timer which connect to initiating contact (see Fig. 4-7).

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* Typical values: 0.05 or 0.1 μf.

TABLE III—PART 2 (*Continued*).—TROUBLE-SHOOTING CHART ELECTRONIC TIMING RELAYS

Trouble	Cause	Remedy
	Long wires from initiating contact located near wires used to energize magnetic control devices and transient voltage induced in these wires by operation of the devices.	Shorten wires to initiating contact; or Separate wires to initiating contact from other wires; or Connect a capacitor* across terminals which connect to initiating contact (see Fig. 4-7).

TABLE III.—PART 3.—TROUBLE-SHOOTING CHART ELECTRONIC TIMING RELAYS

Trouble	Cause	Remedy
Inconsistent timing—successive operations of the timing relay do not give the same time delay. (See text under "Inconsistent Timing.")	Defective tube.	Check tubes, or if unable to do so, try new ones.
	Variations in line voltage outside the limits specified for the device.	If possible, use a better regulated power supply. Otherwise install a constant-voltage transformer.
	Reset time shorter than specified for the device.	Rearrange operating cycle to give longer reset time; or If timing relay is being used near minimum setting of time delay adjustment, use a timing relay with shorter time range, or shorten time range of device by decreasing resistance of the timing resistor.
	Variations in temperature. The type of timing capacitors used in some relays does not permit operation over wide temperature ranges.	Refer to manufacturer's specifications and locate unit so as not to exceed temperature limits.

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* Typical values: 0.05 or 0.1 μf.

TABLE III—PART 3 (*Continued*).—TROUBLE-SHOOTING CHART ELECTRONIC TIMING RELAYS

Trouble	Cause	Remedy
	Bouncing initiating contact. Most contacts bounce on closing. When the contact both energizes a load and initiates the timing relay, the transient voltage appearing across the contacts is introduced in the timing circuit.	Use separate isolated contact for initiating the timer; or Connect a resistor in parallel with the load to suppress the transient voltage. (Typical values: 400 ohms for 115 volts; 1,000 ohms for 230 volts.) (See Fig. 4-7); or Connect a capacitor* across terminals which connect to initiating contact (see Fig. 4-7).
	Bouncing contacts in the general control wiring. One contact initiates the timer and a separate contact energizes the load. The contact that energizes the load bounces and causes a transient voltage to be induced in the supply lines connected to the timing relay.	Use a separate power supply for the timing relay; or Connect a resistor in parallel with the load to suppress the transient voltage. (Typical values: 400 ohms for 115 volts; 1,000 ohms for 230 volts.)

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* Typical values: 0.05 or 0.1 μf.

CHAPTER 5

INSTALLING, MAINTAINING, AND SERVICING PHOTOELECTRIC RELAYS

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The photoelectric relay is one of the oldest and best known of the industrial electronic devices. Its field of application has grown steadily during the past 10 years, and at the present time new uses are being discovered which improve speed, accuracy, and economy. Since photoelectric equipment has been used for counting, sorting, signaling, regulating, measuring, controlling, and inspecting, it is easy to visualize the extent of its applications.

In dealing with photoelectric equipment one is confronted with optics, electronics, and mechanics. But to be able to do a satisfactory job of installation, maintenance, and service, it is not necessary to have a thorough education in each one of these subjects. However, with a knowledge of the maintenance and servicing of electronic equipment, together with information on the specific device obtained from the manufacturer's instructions, and the use of a reasonable amount of good judgment, the majority of common troubles can be prevented or, when they do occur can be readily corrected.

With proper care, photoelectric equipment will give years of reliable service. Even though maintenance is minimized by the use of the very few moving parts, it cannot be neglected entirely. Inadequate maintenance will cause failure of photoelectric equipment as surely as inadequate lubrication of moving parts will break down machinery.

It is well known that there are many different types of photoelectric equipment. This chapter discusses the installation, maintenance, and servicing of only the general-purpose light sources and relays. These are ordinarily used to provide the opening or closing of an electrical circuit by a change of illumination on a phototube.

Installation of Light Sources

In practically all applications of the general-purpose relay, some form of artificial illumination is employed. Although this illumination can be obtained from light sources of several different types, the one most frequently used consists of an ordinary 6-volt automobile headlight lamp and a lens or reflector. For industrial service, the lamp is usually operated at 4.5 to 5 volts in order that a life of several thousand hours may be obtained. When 6 volts are applied, the life expectancy of the lamp is only 100 to 200 hrs.

Most light sources are equipped with 32-candlepower lamps. Unless recommended by the manufacturer, it is not advisable to substitute a 50-candlepower lamp in order to obtain more light. The increase in illumination will usually be small, and the additional heat may cause trouble on units designed for smaller lamps.

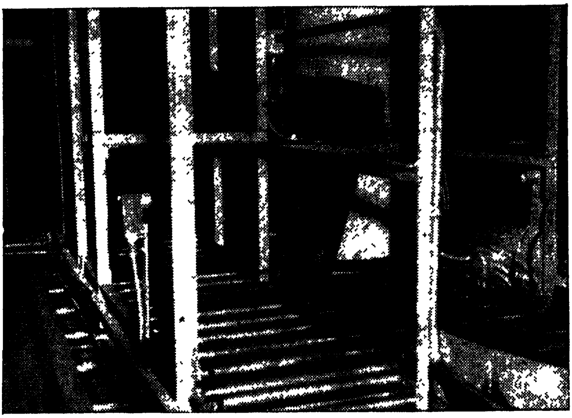

FIG. 5-1. Photoelectric relay directs traffic. Depending on signal, material on conveyor is permitted to continue straight ahead or is diverted down conveyor at its left.

When a light source is installed, it is essential that a substantial support be provided which will be resistant to vibration or shock, in order to keep the narrow beam concentrated on the phototube or its light-collecting lens. Vibration might also cause rapid deterioration of the contact material in the center of the lamp base, and the resulting increase in contact resistance would cause a decrease in lamp intensity. If the light source is located where personnel or mobile shop equipment may strike it, some form of protection should be provided.

Wherever possible, a horizontal beam is to be desired. Dirt will not collect on a vertical lens surface so readily as on one that is facing upward. The light beam should never be directed across a space where columns of steam or vapor may pass through it or condense on the lens. A condition of this sort will cause diffusion of the light and result in possible false operations.

Adequate wire size must *always* be used between the low-voltage winding of the light-source transformer and the lamp to minimize voltage drop in the wire. This voltage drop, if allowed to exceed 0.2 to 0.3 volt, will result in an appreciable reduction in illumination. Number 16 wire or larger is suitable for distances between transformer and light source up to 10 ft, and No. 14 for distances between 10 and 20 ft. For any greater length, a wire size should be chosen that will keep the voltage drop within the limits given above. The current taken by a 32-candlepower lamp is approximately 3.5 to 4 amps.

FIG. 5-2. Focusing light source by adjusting lens barrel in order to obtain maximum illumination at phototube.

Focusing the Light Source

Proper adjustment of the light source is essential in securing the maximum performance of any photoelectric installation. This adjustment, ordinarily referred to as focusing, is performed by varying the distance between the lamp and the lens or the reflector (Fig. 5-2). The best method is to place a piece of white paper at the location of the phototube and then focus the light source until the image of the lamp filament is most clearly defined. Next, the image is thrown slightly out of focus by decreasing the distance between the lamp and the lens or reflector. This produces a uniformly lighted area of maximum intensity. If these instructions are not followed, it is quite possible to have the effective illumination reduced as much as 50 per cent.

The a-c supply voltage to the light-source transformer should be maintained within ±5 per cent of the nominal line voltage. The importance of this is apparent from the fact that the illumination varies approximately three times as much as the supply voltage. For example, a 5 per cent drop in line voltage will produce a 14.5 per cent decrease in illumination and a 10 per cent drop in voltage will produce a 27 per cent decrease in illumination. With a relay installation in which the light change for operation is adjusted for 27 per cent by the intercepting medium, a 10 per cent decrease in voltage would produce the same effect and cause a false operation of the relay. Excessive line-voltage regulation can be greatly improved by the use of a constant-voltage transformer. Commonly available types will maintain the supply voltage to within ±1 per cent for a total line variation of 30 per cent.

Maintenance

Although only a negligible amount of maintenance is required for a light source, it is still something that must not be neglected if reliable service is expected of the equipment. Lamp replacement will have to be made whenever burnout occurs. If some conveyer line or machine may be shut down as a result of a lamp failure, it is much better to replace the lamps on some definite schedule of 1,000 to 3,000 hr instead of waiting until burnout occurs.

Lenses should be cleaned whenever necessary. Frequency of cleaning depends entirely upon the conditions of the atmosphere in which the light source is installed and the position of the lens. In a very dusty atmosphere it might be necessary to clean the lens as often as once a week or less. Under normal conditions, once every 3 to 6 months might be sufficient. Since dust collects readily on the upper side of a horizontal surface, lenses facing upward will require more frequent cleaning than those facing downward or mounted vertically. The method used for cleaning depends upon the nature of the accumulation on the lens. A light film of dust can be removed by an air supply or by dusting lightly with a clean cloth. An accumulation resulting from dirt and oil vapors will have to be cleaned by the use of some solvent followed by soap and water, or by prepared lens or window cleaners. Most lenses can be readily taken out for cleaning by removal of a locking ring. In doing so, precautions should be taken not to disturb the adjustment of the light source.

Periodic inspection should also be made of the light-beam alignment and focus to be sure that they are in proper adjustment.

Photoelectric Relays

The light developed by the source is usually transmitted directly either to the photoelectric relay or to some surface such as a mirror or sheet of paper and then reflected to the relay. The photoelectric unit consists of a phototube, an amplifier circuit employing one or more electronic tubes, and a contactor or relay, the contacts of which are used to control some electrical circuit. Owing to the wide variety of operating conditions imposed on these devices, a number of different types have been made available. These relays differ in regard to sensitivity, time of response, location of phototube in the same case as the relay or separately mounted, type of electronic circuit, and type of enclosure. The light may strike the phototube directly or may be received by a lens and then focused to a small area on the phototube cathode.

Installation

The relay enclosure should always be mounted on a rigid support which is not subjected to any appreciable vibration or shock. Vibration or shock may not only be injurious to the tubes, but may also loosen the leads in the circuit. Where such conditions must be tolerated, some sort of cushioning with rubber, felt, or springs should be provided.

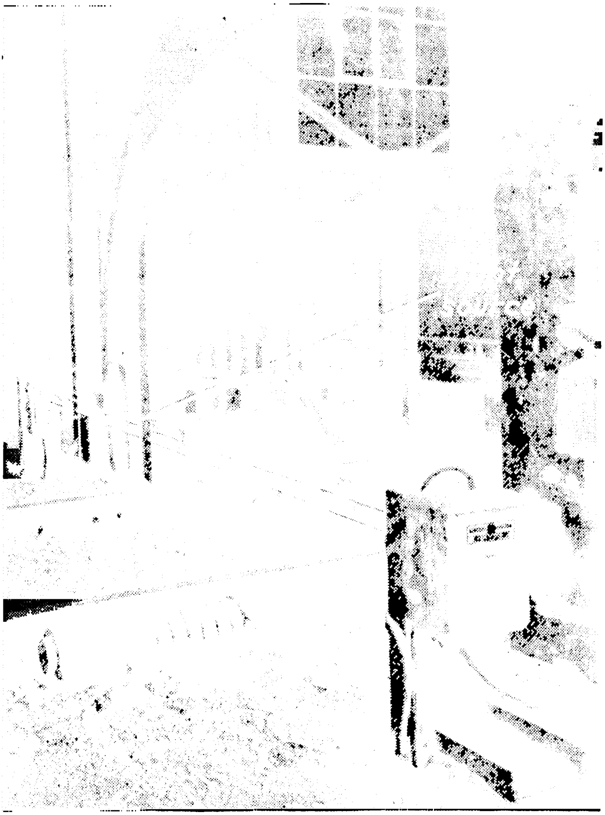

FIG. 5-3. Phototube relay setup for protecting personnel against accidents in coal-preparation plant.

Where a separate phototube holder is used, the same precautions should be applied in its mounting. In locations where it is possible for the holder to be struck by personnel or mobile shop equipment, it is advisable to protect the holder with some form of guard.

Temperature Considerations

The temperature of the air surrounding the relay enclosure should not exceed 40°C unless specified otherwise by the manufacturer. In the case of an extended phototube holder, the temperature of the housing or the air surrounding it should not exceed 100°C for red-sensitive phototubes or 75°C for blue-sensitive tubes. Neither the relay case nor the holder should be mounted directly on a hot surface. This would raise the enclosure temperature by conduction.

Standard controls should not be installed where abnormal atmospheric conditions exist, such as steam, moisture, corrosive vapors, explosive gases, or dust. Where such conditions must be tolerated, special equipment should be used.

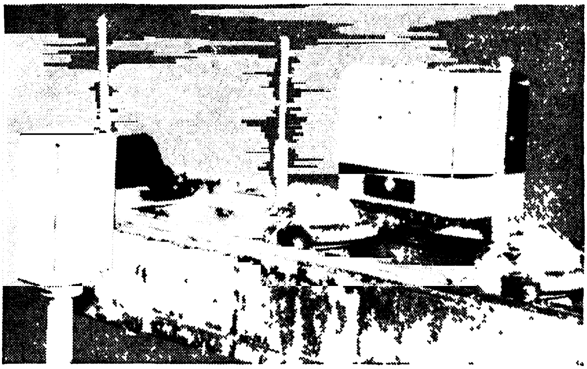

FIG. 5-4. Photoelectric "packaged" relays such as this are inexpensive and are used widely throughout industry to count, control, and limit operations. Here it counts valves leaving a heat-treating furnace.

Extraneous Light

The phototube housing should be located so as to minimize the entrance of any light other than that from the source. On indoor installations care must be taken to exclude extraneous light from large lamp bulbs located in the proximity of the light beam, from daylight coming through a window, or from light, either artificial or daylight, being reflected from mirrors or highly polished surfaces to the phototube. In most cases the proper positioning of the phototube unit or the addition of suitable shades will eliminate the possibility of trouble from these sources. A rough check on the presence of extraneous light can be made by adjusting the relay to its most sensitive setting with the light source off, and then noting whether the relay can be made to operate by passing an opaque object back and forth directly in front of the phototube. The results of a test of this kind are not entirely conclusive because the presence of some stray light can be tolerated if the illumination level from the light source is quite high. However, if the illumination level is low, that is, when the operating distance is near the maximum, then very little stray light can be tolerated.

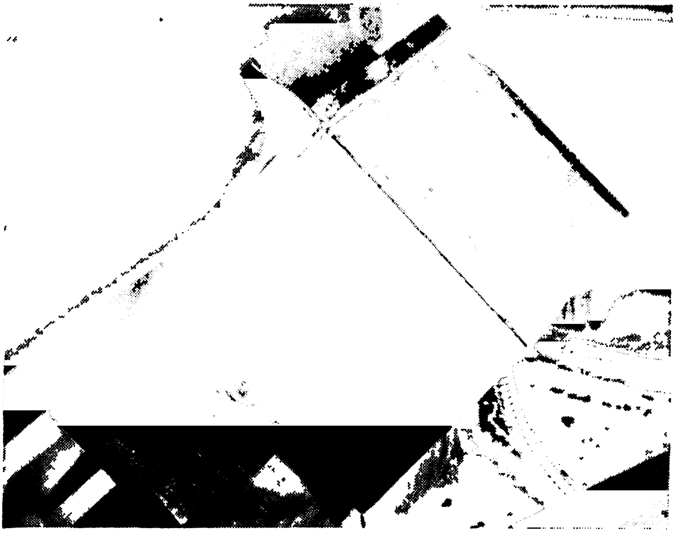

FIG. 5-5. Side register control holds accurate edge alignment for uniform coiling of steel strip. Light beam at right edge makes continuous check on strip's position. Variation of even a few thousandths of an inch is sufficient to start corrective action.

In one case a photoelectric relay seemed to operate satisfactorily during the morning and early afternoon, but occasionally during the late afternoon it would cease to function. Investigation disclosed that the afternoon sun shining through a window was directly in line with the phototube unit and thus provided adequate light to keep the relay energized even though the light beam was cut off.

Because of this extraneous light condition, indoor-type relays are not ordinarily suitable for outdoor use. For this type of service, on short-distance installations (200 ft and less), a long-focal-length lens is quite commonly used with the phototube for the purpose of rejecting most of the stray light without reducing the light from the source. For long-distance operation outdoors, special equipment using modulated light is usually employed.

Wiring Precautions

Because the phototube has a high plate resistance and therefore requires a load resistor of 3 to 10 million ohms, it is essential that the resistance to ground of all circuits associated with the phototube be maintained as high as possible. This includes sockets, cable, and terminal boards. Relays equipped with an extended phototube holder are provided with a special shielded cable which has a high insulation resistance. If a replacement or extension of the cable is made, it should be of the same type, and its insulation resistance should measure at least 500 megohms. It is not advisable to splice this cable but, if it must be done, the splice should be covered with a good quality of rubber tape. Ordinary friction tape should not be used. When shielded cables are spliced, the shields of the two cables must always be connected. Whenever the phototube cable is extended, the time

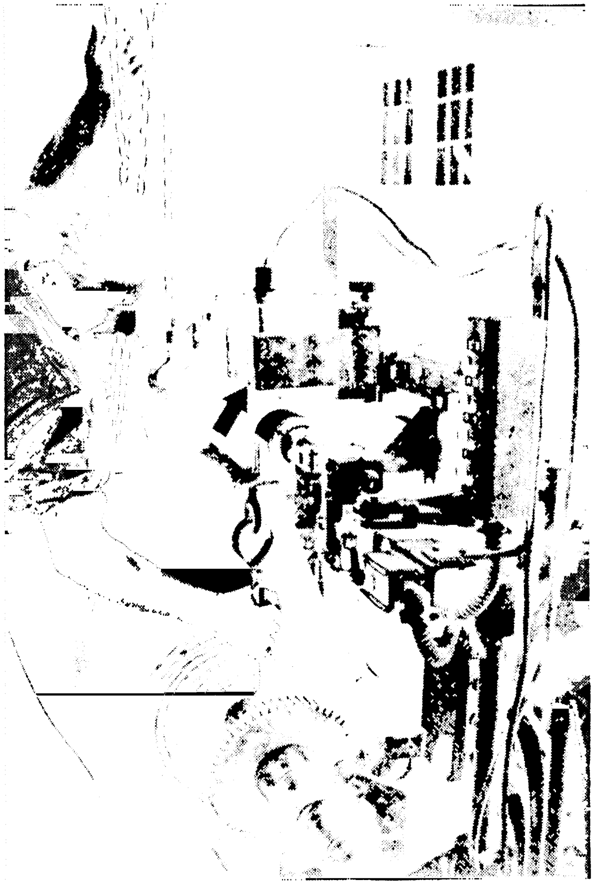

FIG. 5-6. Photoelectric scanning heads and other auxiliary units which require precision adjustments must be protected against mechanical shock or damage. Note sheet-steel guard (arrow) to prevent chain hoist from striking head and disturbing adjustment.

of response of the relay will be made longer, and in some relays the sensitivity will be reduced considerably. The cable to a phototube must always be shielded. Since the phototube current never exceeds 20 μa, the size of the wire is unimportant.

FIG. 5-7. Measuring voltage supply to a photoelectric relay This voltage should be maintained within ±5 per cent of the nameplate rating.

Leads to the phototube should not be run in the same conduit with the power wiring because transient voltages caused by switching in the power circuit may be induced in the sensitive phototube circuit. For the same reason, the phototube leads should not be cabled to the power leads within the case, but should be kept separated as much as possible. It is common practice to design photoelectric equipment with the power circuits and the phototube input circuits separated as much as mechanical construction will permit.

The supply voltage should be maintained within ±5 per cent of the rating stamped on the panel name plate. Continuous operation of the relay at any appreciable voltage above or below its rating is detrimental to tube life. A constant-voltage transformer can be used to compensate for poorly regulated power supply. In most cases this transformer can be used to supply both the relay and the light source. If the line voltage is low but has satisfactory regulation, a small autotransformer can be used to boost the voltage.

It is advisable to provide fuses in the power supply to all relays. Since most relays rarely take more than 50 volt-amperes, the ordinary circuit breakers and fuses commonly used do not furnish adequate protection. A 1-amp fuse should be suitable for most installations.

A number of photoelectric devices use the telephone-type relays with small contacts usually rated about ½ to 2 amp, a-c inductive load. When these relays are used to control a-c magnetic devices, such as small contactors and solenoids, it is usually advisable to place a capacitor of about 0.25 to 0.5 μf in series with a resistor of about 200 ohms across the coil of the magnetic device to reduce sparking at the contacts. This will increase the contact life and is especially desirable for a device being used for high-speed counting operations where contacts make and break rapidly for long periods at a time.

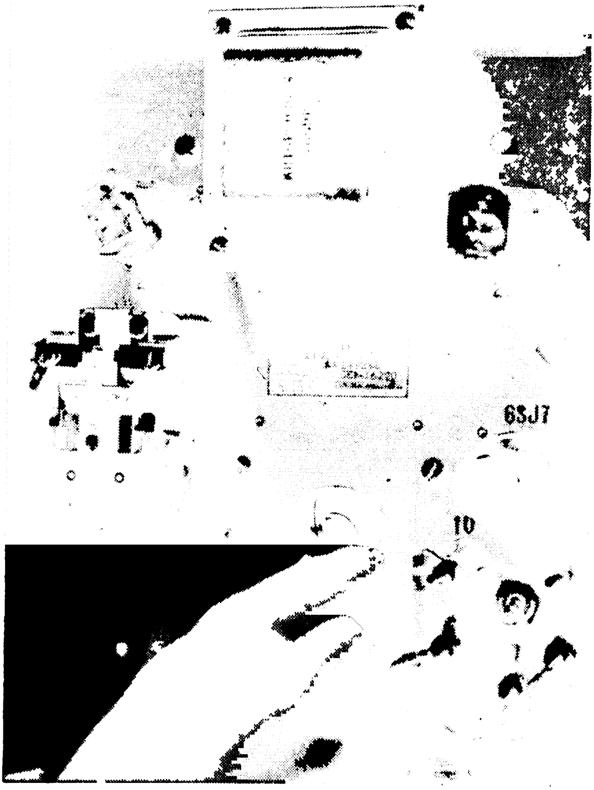

FIG. 5–8. Adjusting illumination-level control of a photoelectric relay is particularly important prior to putting into operation if continued satisfactory performance is to be expected

Adjustment

After the light source and relay have been installed, the equipment should be properly adjusted (Fig. 5-8). It is common practice to direct the light toward the phototube, turn one of the adjustments until the relay operates, and then assume that the equipment is ready to be placed in service. Satisfactory performance might be obtained with this manner of adjustment under certain conditions of operation, but trouble will probably occur later.

The first step in setting up an installation is to focus the light source properly as described previously. *When this is finished, the* phototube or its lens should be in the center of the light-source image and the illumination will be at its maximum. If the installation is to be operated by complete cutoff of the light beam, the next step is to reduce the light by covering the phototube opening or the lens at least 50 per cent with an opaque object, and setting the light level adjustment at the point where the relay just operates. This should be checked several times by gradually cutting off the light from maximum to 50 per cent and, if necessary, making slight readjustments so that the relay operates when the light to the phototube is reduced approximately 50 per cent.

The purpose of this method of adjustment is to provide sufficient safety factor to take care of conditions that may reduce the light and cause false operations. These conditions may be low line voltage, lamp aging, or accumulation of dust on the lens. The percentage of light cutoff for which any installation can be adjusted depends upon the light intensity at the phototube and the sensitivity of the relay. If atmospheric conditions may cause an appreciable attenuation of the light over a short period of time, it is essential that the relay be adjusted to operate when 60 to 90 per cent of the light is cut off. However, in adjusting for this condition of operation, the optimum sensitivity setting of the light-level control should not be approached so closely that small changes in line voltage will produce false operation during the interval when the phototube is dark.

If the relay is to be operated by some translucent material entering the light beam which provides a light attenuation of at least 50 per cent with the beam completely intercepted, then this material should be used instead of an opaque object for making the light-level adjustments as described previously. The relay should be adjusted for operation with the material covering about 50 to 70 per cent of the lens or phototube opening. Operation with material that partly attenuates the light requires better line-voltage regulation than operation with complete light cutoff.

Maintenance

Maintenance of the photoelectric relay is limited primarily to keeping the lenses, phototubes, and phototube circuits clean; occasional inspection of the relay adjustment; adjustment and replacement, when necessary, of contact tips of the magnetic relay; and routine testing of the amplifier tubes and replacing when necessary.

The frequency with which lenses and phototubes, if exposed, have to be cleaned depends entirely upon the conditions in which the *equipment is located (Fig. 5-9). The discussion on lens cleaning for* light sources applies to the photoelectric relay as well. All cables and connections in the phototube circuit must be kept clean and dry. As mentioned previously, this portion of the circuit operates at very high impedance; therefore, precautions must be taken to prevent its exposure to excessive moisture. If appreciable dust collects in the enclosure, an occasional cleaning with an air hose will be beneficial.

Since there will be a gradual decrease in light due to darkening of the lamp bulb, and some change in both phototube and amplifier-tube characteristic, it is advisable to check the relay adjustment occasionally.

Since photoelectric relays are quite often operated up to 400 times a minute, very severe duty can be imposed on the telephone relay or contactor. In fact, under such operating conditions 24 hr a day, many million operations can be obtained in a few weeks' service. For this reason, the relay or contactor should be inspected frequently and suitable repairs, adjustments, or replacements made whenever necessary.

FIG. 5-9. Lenses and other parts of the optical system should be wiped regularly with a soft, clean cloth.

In devices using the telephone relay it is advisable to inspect occasionally the normally closed contacts to determine whether full spring pressure is being applied to the contact tips. In some cases, the wear of the contacts may increase to the point where the armature stop prevents the contacts from receiving full spring pressure. This may be remedied by bending the armature stop to provide $\frac{1}{16}$-in. clearance between the armature arm and the contact spring (Fig. 5-10).

In order to maintain continuous service, a definite schedule should be followed in the testing of tubes. The radio receiving-type tubes can be checked in a conventional tube tester used by radio dealers. A routine check about every 3 to 6 months and the discarding of any tubes that read low should provide practically trouble-free operation. Occasionally a tube may be found which fails to work in a photoelectric relay, but indicates "good" on the tester. This occurs because the ordinary radio tube tester does not check for all the characteristics used by the electronic circuit. Power-output-type tubes such as the *25L6*, *6L6*, *6V6*, *117N7GT*, or *117P7GT*, may exhibit this effect.

At present there is no conventional means for readily testing phototubes. However, when used in proper circuits and not abused by excessive light of high ambient temperature, they will have a life expectancy of more than a year and quite commonly last 2 or 3 years.

External Trouble Causing Failure

When a photoelectric installation ceases to operate properly, it is usually urgent that it be placed back in service with minimum delay. To do this, the serviceman should be well acquainted with the installation and have a general knowledge of how the relay operates. He should also be familiar with service instructions and have a good understanding of the procedure to follow in locating the trouble. His ability to use good judgment and common sense in analyzing the problem is important.

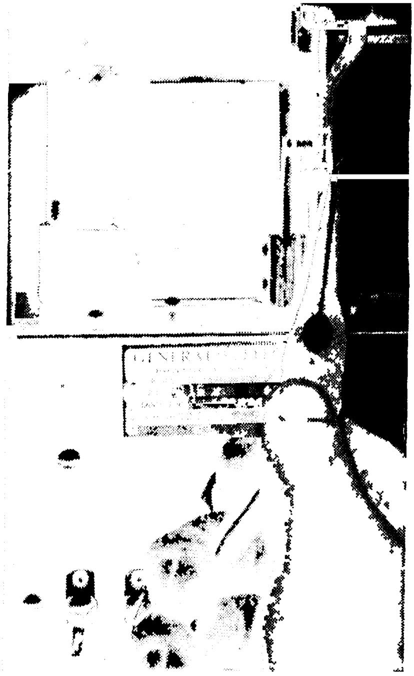

FIG. 5-10. Armature stop of telephone-type relay being adjusted in order to permit contacts to receive full spring pressure.

Before any attempt is made to work on the electronic circuit, a careful analysis should be made of all other possible causes for the failure. Where the photoelectric relay is controlling auxiliary electrical equipment, an inspection to determine if this equipment is functioning properly should always be made. Table IV lists a number of items that should be checked. Although these may seem simple and quite obvious, they are often neglected.

Trouble-shooting Internal Circuits

After all sources of trouble external to the electronic circuit have been thoroughly investigated, the panel should be removed from its case and work begun on it. A visual inspection should be conducted first in order to locate broken leads to resistors, capacitors, or other points in the circuit, and to locate defective parts such as overheated resistors, transformers, or capacitors. A defective resistor can sometimes be detected by severe discoloration; a defective transformer by the presence of the impregnating compound coming out of its windings; and a defective capacitor by the presence of wax or liquid on the outside of the container. When a defective circuit element is discovered in this manner, further analysis should be made to determine if the trouble was caused by the failure of another circuit element. For instance, a short-circuited capacitor or potentiometer could result in the overheating and consequent failure of a resistor or transformer with which it is associated. Each circuit failure presents a different problem and therefore must be analyzed separately.

FIG. 5–11. Voltage measurements being made with a vacuum-tube voltmeter on a photoelectric relay. This instrument is very useful for servicing electronic equipment.

If the visual inspection does not provide a solution to the trouble, then a check on the various circuit elements by means of an ohmmeter to locate such faults as short-circuited capacitors and open resistors or contactor coils may be necessary. When measuring a resistor, be sure that there are no resistors at other locations in the circuit in parallel with the one being measured. Such a situation would give an incorrect reading.

If data are available on the transformer voltages and the d-c potentials at various points in the circuit, the trouble may be soon located by checking these voltages with a suitable instrument. For measuring the d-c voltages, a high-resistance voltmeter having a a resistance of 5,000 to 20,000 ohms per volt should always be used. In some cases, it is even necessary to use a vacuum-tube voltmeter having an internal resistance of 10 to 15 megohms. The type of voltmeter that should be used can be determined readily from the value of resistance across which the measurement is to be taken. To provide accurate readings, the voltmeter resistance should be at least ten and preferably twenty times the resistance of the resistor across which the instrument is placed. For example, to measure the voltage across a 100,000-ohm resistor, the total resistance of the voltmeter should be at least 1,000,000 ohms.

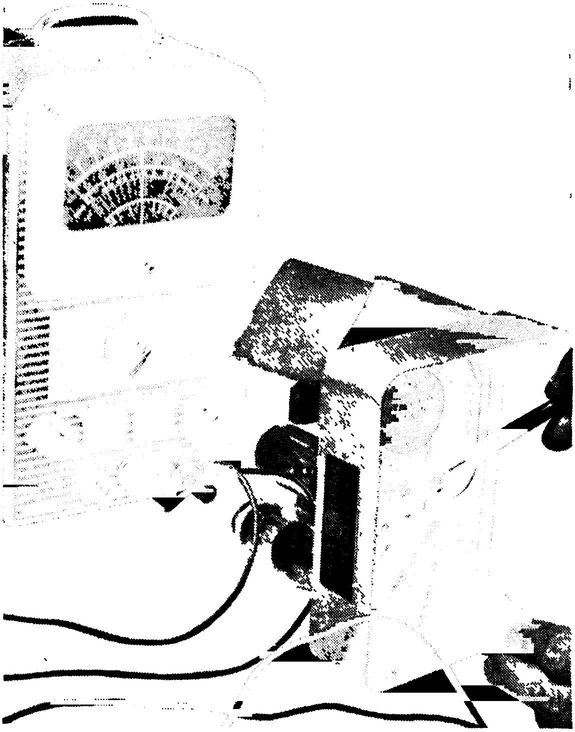

FIG. 5-12. Circuit components of a photoelectric relay being checked with a multimeter. The multimeter is capable of measuring resistance, voltage, and current.

The present demand for smaller and less expensive devices has made it necessary to add the electrolytic capacitor to the list of components. The life of this type of capacitor cannot be expected to be practically indefinite as is sometimes assumed for other types of capacitors. Although the average electrolytic capacitor will give satisfactory service for many years, it is still possible to find occasional failures after about a year of service. In electronic circuits, failures due to overvoltage are practically eliminated because the capacitors are normally operated well below their rating. The operating temperature of the electrolytic is one factor that affects its life. Therefore it is advisable to mount the relay in as cool a location as possible. Where the ambient temperature runs 40°C or slightly more continuously, it will be helpful to drill a few holes in the case for ventilation if the unventilated type is being used for the particular application.

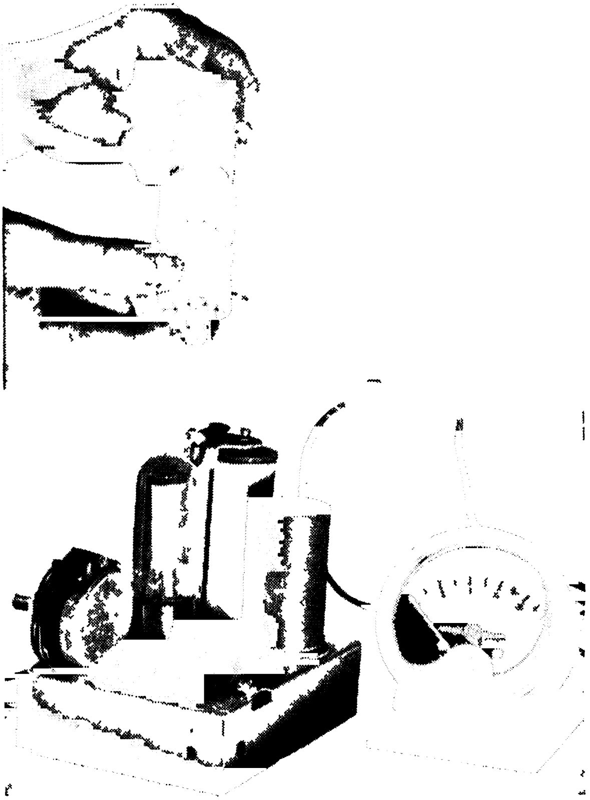

FIG. 5-13. The plate current of a tube is about to be measured by means of a tube-socket adapter and a milliammeter.

When failure does occur, it usually results in the capacitance dropping to zero instead of short-circuiting, as is commonly experienced with these capacitors as used in radio receivers. In many cases the effect of an "open" electrolytic is to permit unfiltered direct current to pass through the contactor and cause it to "chatter."

Special Systems

In addition to the familiar relays already discussed there are many photoelectric devices and systems designed to perform special functions.

The electronic units used in these applications range from simple devices performing some special signaling, controlling, or measuring function to quite complicated equipment which is an integral part of some electrical-mechanical system. The photoelectric pyrometer, outdoor light control, cutoff register control, side register control, pinhole detector, smoke detector, flame detector, contour follower, and weft straightener are typical examples.

Because there are few moving parts in electronic equipment, the problem of maintenance is never very trying. When properly installed and maintained, this equipment will give years of satisfactory service, and, compared with other electrical equipment, greater precision and sensitivity are usually obtained with the electronic devices, without lessening reliability or increasing maintenance. Since all kinds of photoelectric equipment have many characteristics in common, most of the points discussed above and also applying to the special equipment will not be repeated.

Fig. 5–14. Checking the operation of a photoelectric multicolor register control by means of a cathode-ray oscilloscope.

Installation

In practically all photoelectric equipment other than the general-purpose relay, the phototube is located separate from the master control panel. The phototube may be mounted in a holder either alone or with an auxiliary amplifier, or both the holder and a light source may be mounted together on a common support, in which case the unit is called a "scanning head."

Phototube holders and scanning heads should be mounted rigidly with the lens or phototube facing downward whenever possible. Mounting in this position not only minimizes the collection of dust on the glass surfaces, but also reduces the effect of extraneous light. The unit should be suitably protected if, because of its location, it is likely to be damaged or thrown out of adjustment by mobile shop equipment (see Fig. 5-6).

All cable to the phototube must be shielded, with the shield connected to the phototube holder and to the correct point on the control panel. The cable should not be located where it is exposed to water or excessive moisture.

Where a definite length of cable is included with a phototube holder or a scanning head, no appreciable extension should be made unless the instructions with the equipment specify that an extension is permissible.

The installation and conditions of operation for photoelectric relays described above also apply in most cases to the control panel, light sources, and auxiliary units of the special equipment. These devices should be installed so that they are easily accessible for changing lamps and tubes, adjustment of the optical system, and general servicing.

Scheduled Maintenance

All parts of the optical system that transmit or reflect light must be kept clean (see Fig. 5-15). This includes all glass or plastic surfaces such as lenses, prisms, and mirrors. The frequency with which these parts have to be cleaned obviously depends upon the atmospheric conditions in which the equipment operates, and the extent to which the particular photoelectric system will permit a reduction of light before it fails to operate.

The adjustment of the equipment should be checked occasionally. This will help maintain operation at maximum efficiency and forestall any failure due to a gradual change of light or tube characteristics.

If contactors or relays are used in conjunction with the electronic equipment, they should be inspected frequently, and suitable repairs, adjustments, or replacements made whenever necessary. Quite often these magnetic devices are subjected to very heavy use when employed with electronic systems, with the result that millions of operations may be put on them in a short time.

FIG. 5-15. Light-source lenses and all glass and plastic components of photoelectric relay optical systems require periodic cleaning and inspection to avoid false operations

Other maintenance factors were discussed previously under Focusing the Light Source and Photoelectric Relays, pages 74 and 75.

Servicing

In order to service photoelectric equipment efficiently, the serviceman should be familiar with the entire installation and have at least a general knowledge of how the electronic control operates. He should also be acquainted with the procedure to follow in locating trouble, and be able to analyze quickly the unusual problems that occasionally arise.

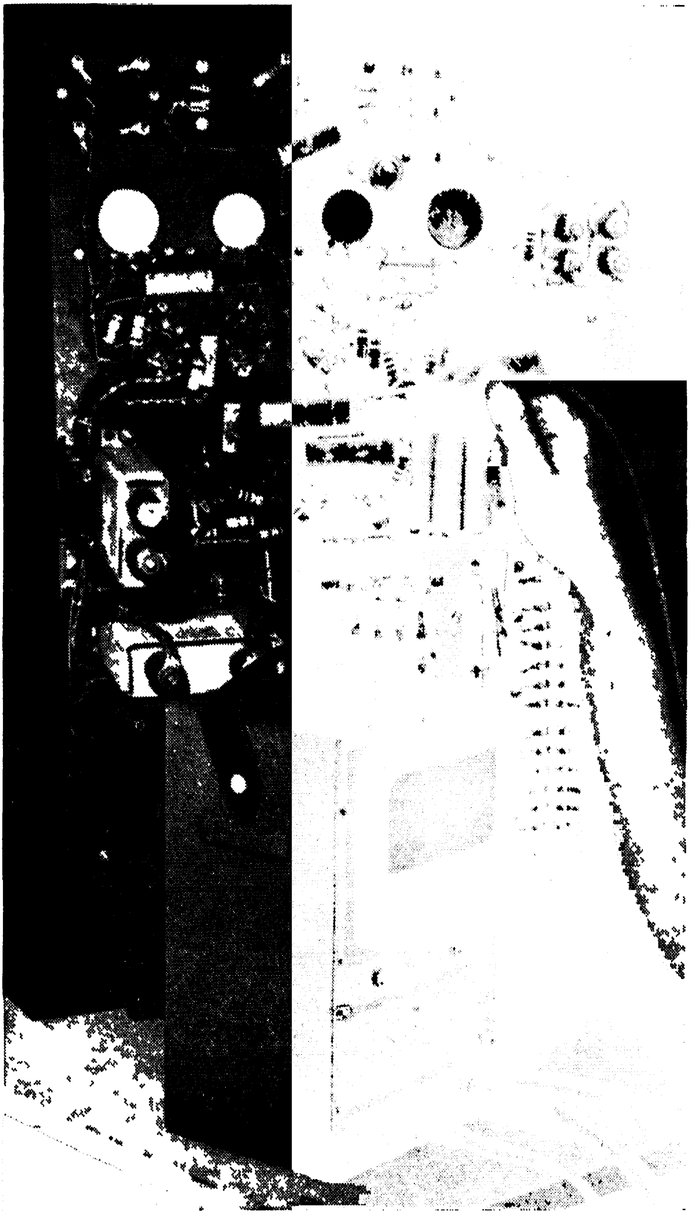

FIG. 5-16. A vacuum-tube voltmeter is used to measure the voltage across a component in one of the circuits of a cutoff register control.

Before attempting to work on the electronic circuit, a careful analysis should be made of all other possible causes for the failure. Table IV lists a number of the common faults that should be initially investigated. In installations where the electronic and mechanical systems are closely associated, a careful investigation should be made of the latter before the trouble is definitely attributed to the electronic equipment. Frequently the electronic equipment is blamed for trouble which is later found at some other location in the system.

After all sources of trouble external to the electronic circuit have been thoroughly investigated, then trouble shooting on the circuit should begin. (Other details of visual inspection and servicing were discussed on page 84.)

If the person servicing the equipment is acquainted with the operation of a cathode-ray oscilloscope, it is one of the best instruments to use for quickly locating trouble. As explained in Chap. 3 on the cathode-ray oscilloscope, its greatest value to the trouble shooter lies in the fact that it enables him actually to see the instantaneous behaviors and relationships of the various voltages throughout the many circuits and circuit elements. Photoelectric systems usually consist of a master control panel into which are fed the signals from auxiliary equipment, such as a scanning head and rotary selector switch. The oscilloscope will provide a visual indication of whether the proper signals are being obtained from these auxiliary units. Then in the master panel the signals can be traced through the various parts of the circuit to the point where the control of the motor, solenoid, or other mechanical device takes place. When the trouble has been traced to a definite portion of the circuit, the defective part can be located with the aid of an ohmmeter and voltmeter.

The defective element should be replaced with one of equal rating and preferably made by the same manufacturer. In case a substitution has to be made, it is satisfactory to furnish resistors of higher wattage rating and capacitors of higher voltage rating, but their respective resistance and capacity values must be the same as the one being replaced. If the proper value of resistance or capacity is not available, the correct value may be obtained by connecting several units in series or parallel. When replacement electrolytic capacitors are wired into the circuit, the polarity must be observed.

Service Instructions for a Typical Photoelectric Relay

The installation to which these service instructions apply consists of a photoelectric relay, a light source, and a magnetic counter. The units are installed in conjunction with a conveyer line to count packages as they pass through the light beam. An elementary diagram of this relay is shown in Fig. 5-17. In this circuit the a-c line voltage is rectified by the tube 1*A* and the resulting d-c voltage, after being filtered by capacitors 1*C* and 2*C* and resistor 7*R*, appears between points 1 and 13. The phototube 2 and the two resistors 1*R* and 2*R* are connected in series across this d-c supply. When light strikes the phototube, current flows through this circuit and the voltage developed across 1*R* raises the grid potential of the amplifier 1*B*. The increase in plate current of 1*B*, which accompanies this grid change, causes the relay to pick up.

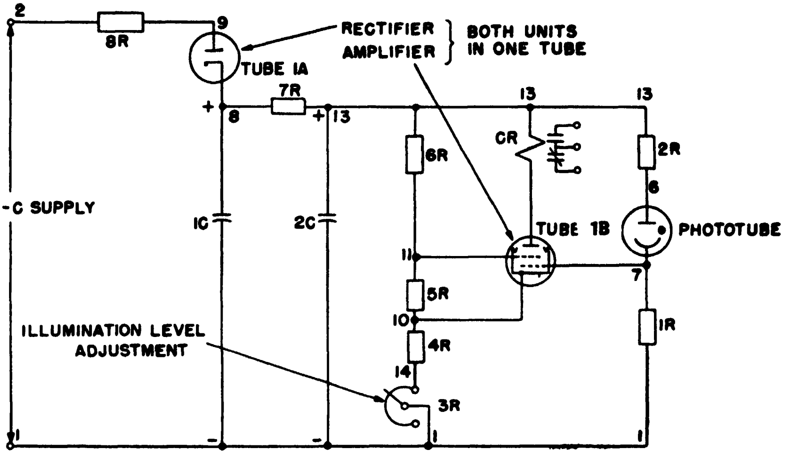

Fig. 5-17. Circuit diagram of typical photoelectric relay.

The potentiometer 3*R* by control of the cathode-to-grid potential, provides a means of adjusting the plate current so that the relay is always dropped out during minimum light conditions. Thus the relay picks up when the light is increased, and drops out when the light is decreased.

The resistors 3*R*, 4*R*, 5*R*, and 6*R* form a voltage divider across the d-c supply to provide the proper potentials to the amplifier tube.

The procedure for servicing the equipment in case the counter fails to register the packages is as follows:

1. Investigate all common sources of trouble as outlined in the service chart. These include failure of the line voltage, lamp burnout, broken or loose connections, failure of the tubes, or improper adjustment of the equipment.
2. Observe the operation of the telephone relay.
   a. If light on the phototube does not cause the relay to pick up, the trouble may be due to an improper setting of the light-

level adjustment, a tube failure, or a fault in the electronic circuit.

b. Cutting all light from the phototube should cause the relay to drop out. If it responds correctly and yet the counter does not operate, the trouble is in either the relay contacts or the counter and its associated electrical circuit. Failure of the relay to drop out indicates either improper setting of the light-level adjustment, a tube failure, or a fault in the electronic circuit.

3. If the preceding analysis indicates circuit trouble, remove the panel from its enclosure and make a visual inspection of the circuit to locate any obvious faults, such as broken or loose connections, or overheated resistors. Connections to the phototube socket in the external holder should also be examined.

Next apply line voltage and check the circuit voltages. With an instrument having at least 5,000 ohms per volt, measure the d-c voltages between points 1 and 10, 1 and 11, 1 and 13, and compare them with the values specified by the manufacturer. If all the voltages are appreciably under the correct values, either the emission of the rectifier element is low and the tube must be replaced, or capacitor $1C$ or $2C$ is defective.

A high voltage between 1 and 13 would indicate an open circuit in the voltage divider $3R$, $4R$, $5R$, and $6R$. Poor contact between the slider of the potentiometer $3R$ and its resistance element would be one point to investigate for an open circuit.

By rotating the adjustment $3R$ over its complete range with the phototube dark, the plate current should change sufficiently to pick up and drop out the relay. If this does not occur, the trouble may be due to any of the following causes:

1. A defective amplifier tube or phototube may cause the relay to remain either picked up or dropped out. Operation of the circuit should be tried with new tubes.

2. The relay coil may be open-circuited.

3. If low leakage resistance (500 megohms or less) develops between points 6 and 7 of the phototube circuit, the relay will not drop out. Failure of this kind may occur where the equipment is being operated under conditions of high humidity or where metallic dust particles may enter the relay case or phototube holder. This leakage condition will be associated with either the phototube socket or the cable to the phototube. The socket can be tested by removing its connections and measuring the resistance between the two terminals to which the phototube connections are normally made. If the resistance is low, a

new socket should be installed. If the trouble is due to the accumulation of metallic dust, there is a possibility that a thorough cleaning may eliminate the leakage condition.

A test can readily be made to determine if the extended phototube holder and its cable are at fault, by disconnecting the cable from the panel and observing the operation of the relay as the adjustment 3*R* is rotated. If the relay picks up and drops out with the cable disconnected and remains picked up with the cable connected, the trouble is associated with the phototube holder or the cable. Leakage can often be caused by deterioration of the cable or by poor splices.

The above example presents an outline of the service procedure for a typical installation. Since the service problem will vary with the type of relay and its application, general service information cannot cover in detail all the possible conditions that might be encountered. Therefore, the serviceman should be thoroughly familiar with the equipment on which he is working, and be capable of making his own analysis of the problems not covered by the general information.

TABLE IV.—SERVICE CHART FOR PHOTOELECTRIC DEVICES AND SYSTEMS

GENERAL: APPLIES TO ALL TYPES OF CONTROL

Trouble	Cause	Remedy
A. Photoelectric system is completely inoperative (initial installation).	1. Incorrect wiring.	1. Check all connections and correct any errors.
	2. Incorrect adjustment.	2. Adjust equipment in accordance with manufacturer's instructions.
	3. Line voltage is not within specified limits.	3. Provide proper line voltage to the equipment. If voltage varies over wide limits, use a constant voltage transformer. If voltage is consistently high or low, an autotransformer can be used to correct voltage.
	4. Fuses blown.	4. Be sure to check all connections before replacing fuses. Do not use fuses larger than necessary to protect the equipment.
	5. Damaged relays or contactors. Contact tips may have been burned or welded owing to improper connections. Relay or contactor may have been damaged during transportation or installation.	5. Repair or replace relay or contactor.
	6. Lamp in light source not lighted.	6. *a*. Replace lamp if burned out. *b*. Investigate the connections to the light source and its transformer, and repair if necessary.
	7. Too low a voltage on lamp. Voltage as measured at lamp (not at transformer) should be within the limits specified by the manufacturer. Usually this is between 4.5 and 5.2 volts.	7. Use larger size wire to light source if excessive voltage drop is occurring between transformer and light source.

TABLE IV—SERVICE CHART FOR PHOTOELECTRIC DEVICES AND SYSTEMS

GENERAL: APPLIES TO ALL TYPES OF CONTROL (*Continued*)

Trouble	Cause	Remedy
	8. Light source not properly focused and aligned with respect to the phototube unit.	8. Make necessary adjustments (see text).
	9. Tubes placed in wrong sockets.	9. Locate tubes in accordance with socket markings.
	10. Defective tubes.	10. Test tubes and replace defective ones. If tester is not available, replace tubes one at a time with a spare.
	11. Light other than that from the source may be reaching the phototube. This may be daylight, light from room fixtures, or reflected light from mirrors or polished surfaces.	11. *a.* Remove interfering light or provide suitable shades. *b.* Relocate phototube unit.
	12. Timing relay for gas-filled tubes may not have timed out.	12. *a.* Wait for completion of time interval. *b.* Repair or adjust if relay fails to time out.
	13. Damaged equipment due to improper handling during shipment or installation.	13. Inspect circuits for broken connections or damaged parts and repair or replace if necessary.
B. Photoelectric device or system does not operate. Has been functioning satisfactorily but suddenly failed.	1. Check items *A*-2, 3, 4, 6, 7, 8, 10, 11, 12 for possible cause of trouble.	1. As indicated in items referred to.
	2. Too low insulation resistance in phototube circuit caused by dirt or moisture. This includes the socket, cable, and connections.	2. Clean or replace cable, sockets, or other defective parts. The insulation resistance between all high-impedance points and ground, with phototube removed and cable disconnected from panel should be 500 megohms or more (see text).

TABLE IV.—SERVICE CHART FOR PHOTOELECTRIC DEVICES AND SYSTEMS

GENERAL: APPLIES TO ALL TYPES OF CONTROL (*Continued*)

Trouble	Cause	Remedy
	3. Contacts of relay or contactor may have welded, or they may have reached the end of their operating life.	3. Replace contacts, or entire relay or contactor. If contacts weld frequently, the current inrush to the load is too great. Either the load must be reduced or an auxiliary contactor installed.
	4. Broken or loose connections between electronic panel and auxiliary control.	4. Repair faulty connections.
	5. Vibration or loose mounting has caused misalignment of light source, phototube unit, or light-reflecting surfaces.	5. Place equipment in proper alignment.
	6. Excessive accumulation of dirt, oil film, or other foreign matter on the lens or other surfaces which transmit or reflect light.	6. Clean the surfaces and inspect at regular intervals.
	7. Defect in the electronic circuit such as *a.* Broken or loose connections. *b.* Shorted or open capacitor. *c.* Open resistors or potentiometers. *d.* Shorted or open transformer winding. *e.* Shorted or open relay or contactor coil.	7. Locate fault and make necessary repairs (see text).

TABLE IV.—SERVICE CHART FOR PHOTOELECTRIC DEVICES AND SYSTEMS (*Continued*)

PHOTOELECTRIC PYROMETER

The photoelectric pyrometer is a radiant-energy responsive device which can be used for indicating, recording, and controlling the temperature of incandescent bodies. The temperature limits for which this device is particularly suited are from 1400 to 3600°F (760 to 1980°C).

Trouble	Cause	Remedy
C. Does not maintain calibration.	1. Check items *A*-2, 3, 10, 11, *B*-2, 5, 6.	1. As indicated in item referred to.
	2. Phototube operating at too high a temperature. Although the phototube can be operated at 100°C without damage, it is advisable to keep below 70°C in order to maintain calibration.	2. Suitable cooling means must be provided. A radiant-heat shield of metal with a bright surface placed in front of the phototube holder is usually helpful. If this is not adequate, air cooling or liquid cooling by means of coils around the holder may be necessary.
D. Instrument does not indicate changes in temperature.	1. Check items *A*-4, 10, and *B*-2, 6.	1. As indicated in item referred to.
	2. Instrument is defective.	2. Repair or replace.
	3. Connections to instrument are open.	3. Repair connections.
	4. Defect in electronic circuit such as *a*. Broken or loose connections. *b*. Shorted or open capacitor. *c*. Open resistor or potentiometer. *d*. Shorted or open transformer winding.	4. Locate fault and make necessary repairs (see text).
E. Temperature indicating portion of circuit operates satisfactorily, but control portion does not.	1. Check items *A*-2, 10, and *B*-3, 4, 7.	1. As indicated in item referred to.

TABLE IV.—SERVICE CHART FOR PHOTOELECTRIC DEVICES AND SYSTEMS (*Continued*)

OUTDOOR LIGHT CONTROL

The outdoor light control is a photoelectric relay used to turn lighting circuits on and off automatically with changes in daylight intensity. It is used for controlling street lights, sign and billboard lights, and radio-tower warning lights.

Trouble	Cause	Remedy
F. Unit does not respond to changes in daylight intensity.	1. Check items *A*-3, 4, 10 and *B*-2, 3, 4.	1. As indicated in item referred to.
	2. Tubes or relay may have been damaged by lightning.	2. Replace tube, or repair or replace relay.
	3. Defect in electronic circuit such as *a*. Broken or loose connections. *b*. Shorted or open capacitor. *c*. Open resistor or potentiometer. *d*. Shorted or open relay coil.	3. Locate fault and make necessary repairs (see text).
G. Illumination-level adjustment has to be changed frequently to maintain operation at the proper light level.	1. Defective amplifier tube.	1. Replace tube.
H. Light level at which relay operates varies appreciably from day to day.	1. Improper location of light control.	1. Control should be located so that rays of sun never shine on phototube. Control should face north where north of equator.
I. False operations occur during the daytime.	1. Improper location of light control.	1. Control must be mounted high enough and away from moving objects in order to prevent temporary shadows from being cast on phototube, thereby causing false operations.

TABLE IV.—SERVICE CHART FOR PHOTOELECTRIC DEVICES AND SYSTEMS

OUTDOOR LIGHT CONTROL—(*Continued*)

Trouble	Cause	Remedy
J. The lighting circuit controlled by the unit is switched on and off rapidly.	1. Improper location of light control.	1. This condition may be caused by the controlled lights shining on the phototube. Change location of control unit so this does not occur.
	2. Filter capacitor in rectifier of electronic circuit is open. This will cause relay to chatter.	2. Replace filter capacitor.

SIDE REGISTER CONTROL

As a continuous strip of metal, paper, or cloth is fed through a machine for processing, it is often necessary to maintain accurate lateral alignment of the material edge. A scanning head consisting of a phototube and a light source develops an electrical signal indicative of the deviation of the material from its correct position. This signal is amplified electronically and used to control a motor which operates a mechanism for providing lateral movement of the strip. Thus, as the strip tends to shift from side to side, the restoring signal always maintains the strip position within very close limits.

Trouble	Cause	Remedy
K. Entire control is inoperative, that is, the correction motor does not run when the material moves away from the point of correct register.	1. Check items *A*-3, 4, 6, 7, 10 and *B*-4, 5, 6.	1. As indicated in item referred to.
	2. Incorrect adjustment of electronic control.	2. Adjust control in accordance with manufacturer's instructions.
	3. The electrical and mechanical part of the system controlled by the electronic equipment may be at fault.	3. Inspect all motors, generators, push-button stations, contactors, mechanical drives, etc., and make any necessary repairs.
	4. Defect in the electronic control.	4. By means of a cathode-ray oscilloscope or other suitable instrument, try to determine the general location of the trouble, that is, whether it is in the scanning head, control panel, or other auxiliary control.

TABLE IV.—SERVICE CHART FOR PHOTOELECTRIC DEVICES AND SYSTEMS

SIDE REGISTER CONTROL (*Continued*)

Trouble	Cause	Remedy
L. Material oscillates back and forth about the point of correct register. This condition is commonly referred to as "hunting."	1. Sensitivity too high.	1. Reduce sensitivity.
	2. Antihunt adjustment is not set correctly.	2. Adjust per manufacturer's instructions.
	3. Positioning mechanism has developed backlash.	3. Such factors as loose mechanical linkages, play in gears, and loose couplings will produce hunting and reduce the accuracy that can be maintained.
	4. "Dead" zone too narrow.	4. Increase width of "dead" zone.
M. Material is maintained in approximate register, but is not being held to the accuracy that has previously been obtained.	1. Check items *A*-2, 3, 7, 10, and *B*-5, 6.	1. As indicated in item referred to.
	2. Rate at which material deviates from correct register may be greater than the ability of the machine to correct.	2. Change the positioning mechanism to provide greater correcting speed, or decrease the speed at which the material passes through the machine so as to reduce its rate of side motion.
	3. Backlash in positioning mechanism.	3. Same as *L*-3.
	4. Material is fluttering up and down at scanning head.	4. Provide a shoe or roller to hold the material in place.

CUTOFF REGISTER CONTROL

In many processes, paper, on which wrapper or bag designs have been previously printed, passes through a machine where it is cut, folded, perforated, or otherwise processed. In order to have the wrapper or bag cut in proper relation to its printing, the knife or cutter must be accurately synchronized with respect to the motion of the paper. Photoelectric equipment when applied to these machines is used to detect minute errors in the relationship between the cutter and the paper feed, and to supply a correcting signal to a mechanical device which makes the necessary correction. The signal for determining the error is obtained photoelectrically from register marks printed on the paper in a definite relationship to the wrapper or bag design.

Trouble	Cause	Remedy
N. The equipment does not correct for errors in register.	1. Check items *A*-2, 4, 6, 7, 10, and *B*-3, 4, 5, 6.	1. As indicated in item referred to.

TABLE IV.—SERVICE CHART FOR PHOTOELECTRIC DEVICES AND SYSTEMS

CUTOFF REGISTER CONTROL (*Continued*)

Trouble	Cause	Remedy
	2. Register marks do not have sufficient contrast with background.	2. *a*. Provide greater color contrast between register mark and background. *b*. Try a blue-sensitive phototube if the red-sensitive tube is being used.
O. Material is being corrected by the control, but the correction does not seem to be adequate. It is continually going out of register in one direction.	1. Incorrect adjustment of the electronic control.	1. Adjust per manufacturer's instructions.
	2. Contactors or relays providing the space and velocity correction, may be defective.	2. Repair or readjust.
	3. Incorrect change gears, resulting in motor providing correction in one direction only.	3. Use change gears which will permit motor to provide correction in both directions
	4. Gear ratio between correcting motor and differential or other correcting mechanism is not correct.	4. Correcting motor should be geared to provide between 2 and 3 per cent change in paper feed for variation in motor speed from zero to maximum.
	5. Excessive tension on material. This causes abnormal slippage in the feed rolls which is greater than the correcting capabilities of the machine.	5. Reduce tension. For best operation, tension on material should be maintained substantially constant regardless of roll diameter.
P. Material is continuously being alternately advanced and retarded about the point of correct register.	1. "Dead" zone of rotary selector switch is too narrow.	1. Widen "dead" zone. Refer to manufacturer's instructions.
	2. Too much space correction is being applied.	2. Reduce space correction. Refer to manufacturer's instructions.
	3. Register marks are not spaced accurately.	3. The printing cylinder must be provided with accurately spaced register marks.

TABLE IV.—SERVICE CHART FOR PHOTOELECTRIC DEVICES AND SYSTEMS

CUTOFF REGISTER CONTROL (*Continued*)

Trouble	Cause	Remedy
	4. Paper underneath scanning head may be fluttering and causing false signals.	4. Provide a shoe to hold paper flat at this point.
	5. Printing adjacent to register marks may be causing false signals.	5. Register marks must be located so there is a separation of at least 2 in. between the marks and any printing in line with them.
Q. Material is maintained to approximate register but is not being held to the accuracy which the machine is capable of holding.	1. Check items *A*-2, 7, 10 and *B*-3, 5, 6.	1. As indicated in item referred to.
	2. Register marks are not spaced accurately.	2. The spacing between register marks must be extremely accurate. Distance between marks must not vary more than one-fifth of the total accuracy which it is desired to maintain.
	3. Insufficient number of register marks.	3. If machine and electronic control are capable of providing good accuracy, then improved results will be obtained as the spacing between marks is decreased. A space of about 2 to 4 in. is practical.
R. In two-way register control employing contactors, both thyratrons fire simultaneously when signal is received from scanning head.	1. "Dead" zone of selector switch is too narrow, causing contacts to both thyratrons to be closed when corrective signal is received.	1. Widen "dead" zone by adjusting selector switch contacts in accordance with instructions.

CHAPTER 6

INSTALLING, MAINTAINING, AND SERVICING ELECTRONIC MOTOR CONTROL

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Although there are specific cases where tubes may be used with a-c motors, adjustable-speed d-c drives provide by far the greatest field for application of electronic tubes in motor-control circuits. Direct-current motors may be controlled by tubes in two ways: (1) where the entire motor power is supplied through power rectifier tubes from an a-c line and (2) where the armature power is obtained from a d-c generator or other source, and tubes are used to excite and control the field of either the generator or the motor, or both.

Although this chapter deals primarily with the former, the problems involved in either of these two systems or in any combination of several motors and their control are similar. This chapter may, therefore, be used as a guide in working with any of these systems.

Installation

Before starting the actual installation of electronic control, it is well to be sure that it is properly located and that the proper material has been accumulated. The connections and conduit runs can be made more easily and with greater facility if a little time is spent in becoming familiar with the various items and how they fit together to make the complete drive. This, together with a few simple checks, will help make installation a short job.

Location of Equipment

One of the best ways to obtain long life and trouble-free operation is to locate the equipment so that

1. It will not be subjected to temperature variations beyond the limits for which it is recommended;
2. It will not be subjected to vibration unless it is especially designed to withstand it;

3. It will be protected against dirt, oil, excessive humidity, and corrosive atmospheres.

Temperature

Electronic equipment has definite temperature limitations the same as any other electrical equipment. Most motors, transformers, contactors, and capacitors are designed to operate in a maximum ambient temperature of about 104°F (40°C). Most electronic equipment, including mercury- or gas-filled tubes, has this same upper limit.

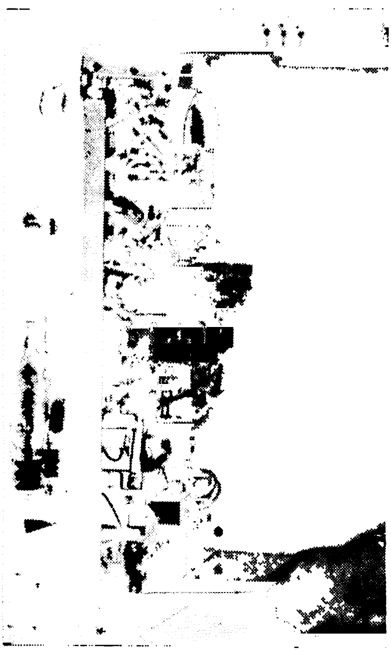


FIG. 6–1. Installation and maintenance of electronic motor control should be methodical and well planned.

Most electronic equipment, unless it has mercury-type tubes, will operate in ambient temperatures that are below zero. Equipment with mercury-filled tubes, though, should not be operated in ambients below about 50°F unless special heating units are provided.

The ventilating openings usually provided on tube controls should be kept free so that air may circulate. This is particularly important in high ambient temperatures

Vibration

Constant vibration may cause terminals to loosen or wiring and parts to crystallize and break. Vibration should be avoided if possible by mounting the equipment where there is no noticeable movement. If it is necessary to mount equipment where vibration is present, it may be necessary to provide springs or rubber bushings to reduce its effect. Sudden shock may also be reduced in this way. It is important that connecting leads be made quite flexible if vibration is present.

Atmospheres

Dirt, oil, excessive humidity, and corrosive fumes all are enemies of electrical components and should be guarded against. Special baffling should be provided if the control is to be mounted where large amounts of dirt or dust may enter the equipment. Splash or drip shields should be installed if water, oil, or other liquid is likely to splash or drip over the panel, motor, or transformer. Oil or water on components may cause a corrosive action and result in open circuits or short circuits. Tropical climates or other extremely humid atmospheres, as well as atmospheres in which acid or other corrosive fumes are present, require special components unless the equipment can be mounted in an area where the atmosphere is controlled. If the equipment is subjected to these conditions, improper operation may result because of leakage paths across high resistance or because of other corrosive action on the various parts.

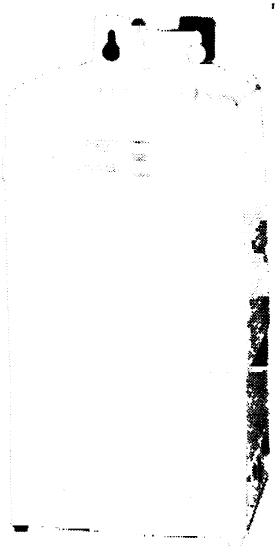


Fig. 6–2. Anode transformer of standard construction supplies power tubes and 110 volts for filament transformer and magnetic control devices.

Identification of Material

A complete drive consists of the following items:

1. A fused disconnecting switch.
2. An anode transformer.
3. The main control panel with the necessary tubes.
4. A control station.
5. A shunt-wound d-c motor.

These items should be checked in detail against the purchase order and the interconnection diagram to be sure that they are correct.

The fused disconnecting switch is used to isolate the anode transformer and the entire circuit from the main power line. Sometimes a magnetic contactor may be included with the manual switch so that power to the anode transformer may be controlled by push buttons. The voltage rating of this switch should be equal to or higher than the a-c voltage. The current rating of the switch and fuses is based on the primary kva rating of the anode transformer.

The current ratings of the fuses should be approximately 250 per cent of the transformer rating. The following formulas show the method for calculating fuse size:

Single-phase transformer:

$$\text{Fuse size in amp} = \frac{\text{transformer primary kva} \times 2{,}500}{\text{a-c line voltage}}$$

Three-phase transformer:

$$\text{Fuse size in amp} = \frac{\text{transformer primary kva} \times 1{,}500}{\text{a-c line voltage}}$$

In both cases the fuse should be the standard size nearest to the calculated rating. *Example:* The transformer for a 1-hp motor is rated 1.65 primary kva. If the line voltage is 220 volts single-phase, the calculated fuse size is 18.75 amp. A 20-amp fuse should be used.

The anode transformer takes power from the a-c line and changes it to a voltage which, when rectified by the thyratron tubes, will be suitable for use on the armature and field of a standard d-c shunt-wound motor (see Fig. 6-2). Also, it usually supplies (from a separate winding) 110 volts for tube filament transformers and magnetic control devices. The primary windings will change for different line voltages, but the secondary connections for single-phase equipment will be the same as shown in Fig. 6-3.

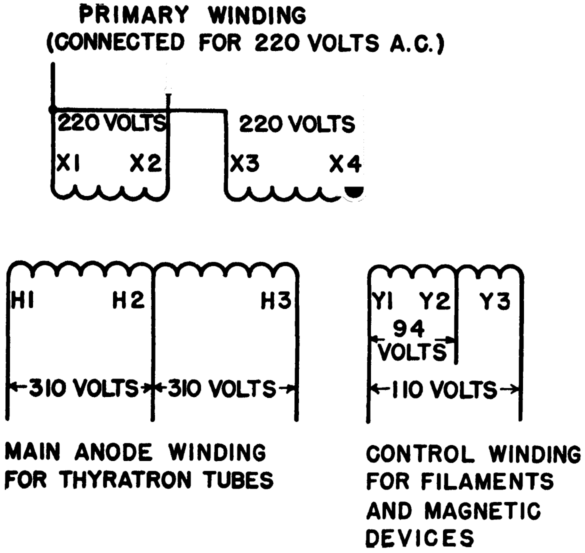

PRIMARY WINDING
(CONNECTED FOR 220 VOLTS A.C.)
220 VOLTS
X1
X2
220 VOLTS
X3
X4
H1
H2
H3
310 VOLTS
310 VOLTS
Y1
Y2
Y3
94 VOLTS
110 VOLTS
MAIN ANODE WINDING FOR THYRATRON TUBES
CONTROL WINDING FOR FILAMENTS AND MAGNETIC DEVICES

FIG. 6-3. Elementary diagram of a typical single-phase anode transformer.

Three-phase or two-phase anode transformers are similar to the single-phase units, but have more primary leads for connection to the polyphase lines and more secondary leads for connection to the larger number of thyratron tubes. The main anode winding has a different voltage than the single-phase transformer. The control winding remains the same as in the single-phase transformer.

The main control panel consists of three major parts:

1. The rectifiers for the armature and field.
2. The electronic control circuits.
3. The magnetic control devices.

The rectifier for armature power is usually of the thyratron type using phase-shifting control so that the armature voltage may be varied during starting and operating. The field rectifier, however, may be of either the phanotron or the thyratron type. A phanotron rectifier is used to provide a fixed voltage output when the motor field is not to be adjusted. A thyratron rectifier similar to the armature rectifier is provided when the motor field is to be adjusted.

Control of phase shifting of the armature or armature and field rectifiers is accomplished through the electronic control circuits. A further analysis of the operation of these circuits will be made later.

Several magnetic control devices are necessary for protection and operation of the drive. A cathode protective timer prevents the flow of motor current for a definite time after the tube filaments have been energized. A field-loss relay prevents starting the motor without field power and will shut down the equipment if the power fails during operation. An overload relay protects the motor against overheating due to overloads. In addition to these protective devices an armature contactor of either the nonreversing or the reversing type is provided. A dynamic braking contactor, as well as other magnetic control relays, may also be included.

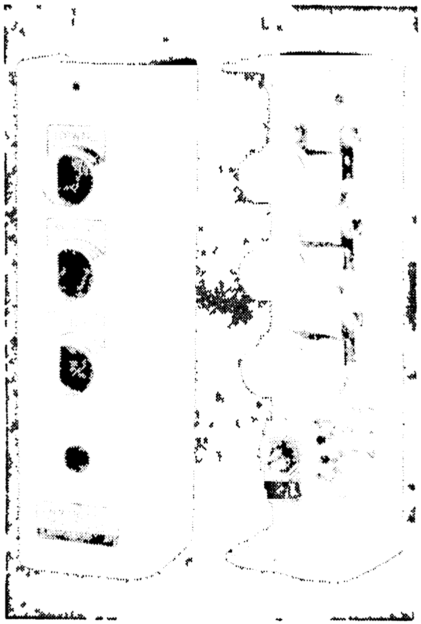


Fig. 6-4. Thy-mo-trol control station with cover removed showing a single-speed control potentiometer.

The control station may consist of only a START and a STOP, or a FORWARD, a REVERSE and a STOP push button, and a single-speed control potentiometer (see Fig. 6-4). A more complicated system of push buttons or limit switches and several speed-control potentiometers may be used, though, if some special operating sequence is required. The interconnection diagram will usually show all devices of this type.

The d-c motor consists basically of an armature and a field (see Fig. 6-5). A commutating field and a stabilizing series field are almost always added, however, to obtain good commutation and stable operation.

Although most shunt-wound d-c motors are alike internally, the terminals may be brought out in several different ways. The armature and commutating field are always connected internally so that only one side of the armature and one side of the commutating field are brought out. Some motors bring out all six leads to allow flexibility, while others bring out only those actually needed for a particular type of operation. For nonreversing motor operation it is necessary to bring only three leads to the control. For reversing operation it is necessary to connect the shunt and the series fields permanently and to reverse only the armature leads. Figure 6-6 shows connections for motors having three, five, or six leads brought out.

FIG. 6-5. An open, horizontal, ball-bearing d-c motor designed to operate on rectified power.

It is important to be sure that the motor has been designed (or it is known to be suitable) for operation on a rectifier, otherwise overheating or poor commutation may result.

A smoothing reactor is sometimes furnished in addition to the items mentioned. This helps to smooth the ripple current that flows in the armature circuit. If a reactor is used, it should be connected external to the panel in series with one of the motor armature leads.

Interconnection of Equipment and Preliminary Checking

Figure 6-7 shows the proper connections to be made between the various units. It also has notes that may be helpful in making connections properly.

The anode transformer, the motor, and the control station all should have an individual conduit run to the main control panel. The wire sizes should be in accordance with NEMA standards and code requirements. If the cables are over about 50 ft long, it may be necessary to use larger wire to prevent excessive voltage drops.

The line voltage and frequency rating on the name plate of the anode transformer should be the same as the power supply. It is important that the secondary connections of the anode transformer be made *exactly* as shown on the diagram. Otherwise, the phase relations of the voltages will not be correct, and the equipment will not operate properly. On two- or three-phase anode transformers the phase rotation of the power supply should be the same as indicated on the diagram.

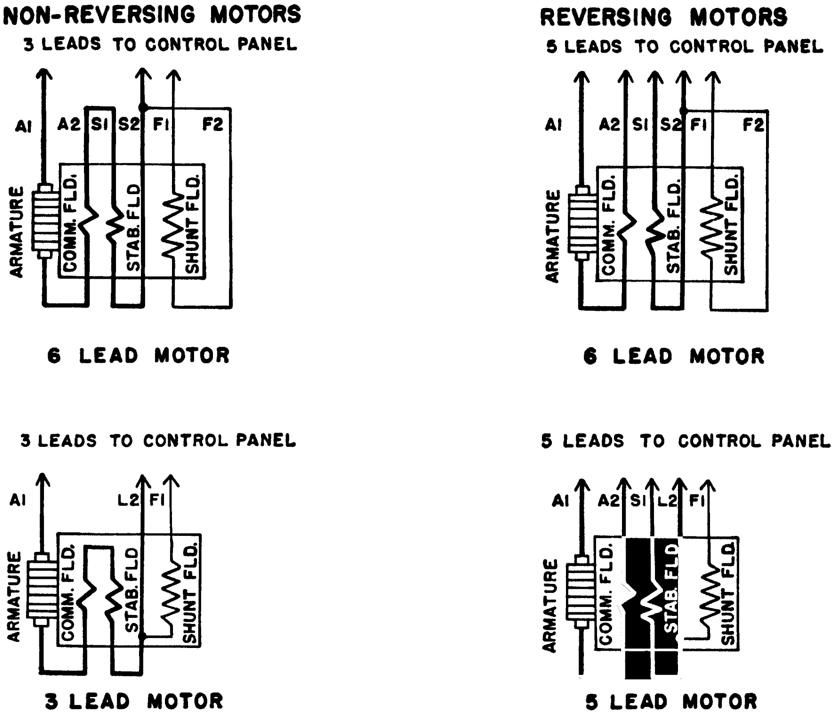
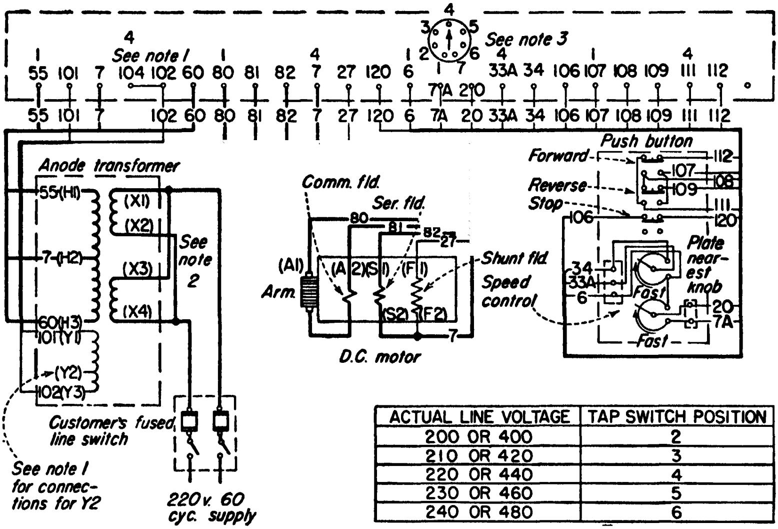


FIG. 6–6. Diagrams showing variations in motor connections. All motors have the same windings. The six-lead motors have all leads brought out, while the three- and five-lead motors have windings connected internally.

The control panels are often designed to cover a range of motor horsepower sizes. Also, a particular panel is designed to be used with several different types of motors of the same horsepower size. Because these differences in motors may affect both the armature and the field circuit, it may be necessary for the contractor or customer to install the overload relay heater, the field-loss relay coil, and the speed-limiting resistor in the control panel. The instruction book furnished with the equipment should give this information in more detail.

Filament Voltage

If maximum tube life is to be obtained, the filament voltage of the thyratron tubes should be held to within ±5 per cent of their ratings. Many industrial power lines, however, have voltage levels that are as much as ±10 per cent from their nominal ratings. For example, a 440-volt rated line may actually have an average voltage of 470. This would be about 7 per cent high. The filament voltage applied to the tubes under this condition is *above* the 5 per cent allowable.



ACTUAL LINE VOLTAGE	TAP SWITCH POSITION
200 OR 400	2
210 OR 420	3
220 OR 440	4
230 OR 460	5
240 OR 480	6

NOTE 1. For 60-cycle operation, 102 on panel is connected to 104 on panel. For 50-cycle operation, remove jumper from 102 to 104 and connect transformer lead Y2 to terminal 104 on panel.

NOTE 2. Connections shown are for 220-volt operation. For 440-volt operation, connect lines to transformer leads X1 and X4 and connect transformer lead X2 to transformer lead X3.

NOTE 3. For maximum tube life, tap switch of transformer T3 on CR7507G146A panel should be set in a position corresponding to the actual line voltage in accordance with table above.

FIG. 6–7. Line-voltage variations can be compensated for by transformer tap switch. All interconnections must follow diagram exactly to maintain phase relations.

Adjusting taps are provided on the thyratron filament transformer or on a control transformer so that the tubes will be provided with the correct voltage, even though the line voltage is as much as 10 per cent from nominal. If the line voltage is more than 10 per cent below or above the rating of the anode transformer, a special transformer will be required to obtain satisfactory operation. (*For any particular tap setting, the line voltage should not vary more than ±5 per cent.* If there is any doubt as to the amount of variation, the tap should be set on the high rather than on the low side, as *overvoltage* will not damage the tubes so quickly as will *undervoltage.*)

FIG 6–8 Instruments for testing electronic motor control include volt-ohmmeter and cathode-ray oscilloscope

After all interconnections have been made and thoroughly checked, the tubes should be placed in the sockets that bear the same number as the tube. *The anode caps or leads, however, should not yet be connected to the main power tubes.*

Initial Start

Unless an error has been made in the interconnecting wiring, the tubes will light as soon as the line switch is closed. Different thyratron tubes, depending on whether they are of the mercury-vapor type or of an inert gas-filled type, or a combination of the two, require different starting methods. Mercury-filled tubes, in general, require a heating time of about 20 min when first installed. The instruction book covering an equipment will give detailed instructions concerning the heating time for the particular tubes used. It is important to follow these instructions, because *failure to observe either the initial warm-up time or the required heating time on future starts will greatly shorten the life of the tubes.* After the initial warm-up time has elapsed, power should be removed and the anode caps, or leads, should be connected to all tubes.

The disconnecting switch should now be reclosed, and the speed-adjusting potentiometer on the control station should be set in the minimum speed position. After the normal heating time of the tubes has elapsed, the motor can be started with the START push button and the speed can be increased by turning the speed-adjusting potentiometer. If the motor fails to operate or if the control appears abnormal, all push-button and motor connections should be thoroughly checked again for errors. Remember that the equipment was thoroughly tested and operated before it left the factory.

The direction of rotation of the motor, if it is connected in accordance with Fig. 6-7, is, for normal or forward operation, generally counterclockwise to one facing the commutator end. The armature leads, *A*1 and *A*2, should be reversed if the opposite direction of rotation is required. Where five leads are connected to the panel for reversing operation, there is very little chance of error in making this change; but where only three leads are brought to the panel, it is important to be sure that only the two armature leads are actually reversed. If only three leads are brought out of the motor, it will be necessary to change the leads internally. Figure 6-6 shows a three-lead motor. To obtain opposite rotation, the lead connecting the commutating and stabilizing field should be broken. Lead *A*1 should be connected to the stabilizing field, and the open end of the commutating field should be taken to the control panel.

Most panel adjustments are made and sealed in the factory to meet average operating conditions. Because of variations in manufacture of the motor and speed-adjusting potentiometer, however, it is not possible to make all the operating adjustments.

Minimum- and maximum-speed adjustments are usually provided so that the speed-adjusting potentiometer will cover the speed range required by the motor. The minimum-speed adjustment should be

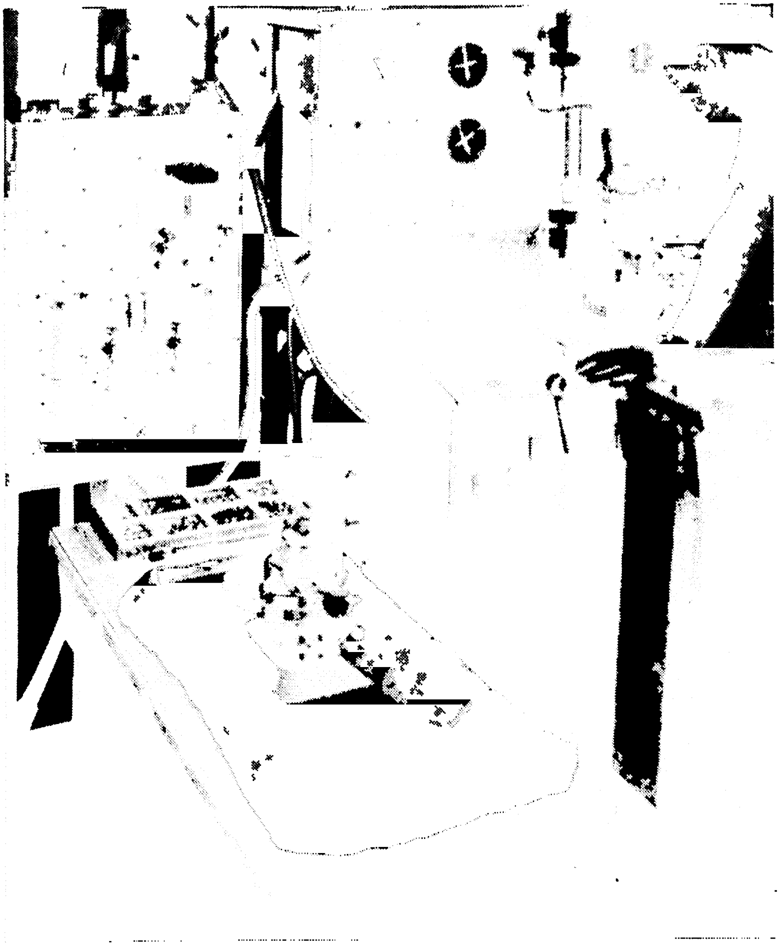


FIG 6–9 Electronic-motor-control drive speeds testing of airplane propeller governors at Nash-Kelvinator's Detroit plant Direct-current motor operates over range 900 to 3,000 rpm Characteristics of the electronic motor control make it ideally suited for this production-line testing application.

made by setting the speed-adjusting potentiometer in its minimum-speed position and adjusting the minimum-speed potentiometer to give that desired minimum speed. If the control provides adjustable armature voltage, but fixed field voltage, the maximum speed of the motor may be set with the speed-adjusting potentiometer in its maximum-speed position by adjusting the variable resistor usually connected in series with the motor field. The "armature voltage potentiometer" may also be adjusted to obtain small changes in top speed. If the control provides both adjustable armature voltage and adjustable field voltage, the top speed can be set by adjusting the maximum-speed potentiometer. It is important to be sure that the maximum speed set in either case is not higher than the name-plate rating of the motor.

The remainder of the panel adjustments should not be touched if the drive performs satisfactorily. If the drive accelerates too slowly, or perhaps too quickly, the "current-limit potentiometer" may be readjusted to obtain the desired start. If the speed regulation at low speeds is not correct, the *IR* compensation or speed-regulation potentiometer may be adjusted to give the required regulation. Panel instruction book should give details.

Preventive Maintenance

Because electronic control has, in general, very few moving parts, it does not require the same periodic attention that must be given to rotating or other moving machinery. About the only preventive maintenance that need be given this type of equipment is an occasional inspection to be sure that terminals or leads are not loosening because of vibration, and that dust, dirt, or oil is not collecting on the panel or auxiliary components. It is well, also, to test the vacuum-type tubes and visually to inspect the thyratrons or other gas-filled tubes to be sure that they appear to be firing.

If the speed-control potentiometer is continually operating in an automatic cycle, periodic inspection or even periodic replacement of the potentiometer unit should be made.

Trouble Shooting

Although the electronic control circuits may appear quite complicated and difficult to service, most of the troubles may be easily located and remedied. Table V includes the troubles most likely to occur.

Electronic motor control is similar to other types of electronic control in that practically all the troubles encountered are relatively simple and easily repaired with very little knowledge of the circuits, and without elaborate instruments and equipment. In order to be prepared to meet *any* trouble that might arise, however, one must know the circuits sufficiently well to be able to isolate the trouble with the help of the necessary instruments.

Instruments

The following instruments should be considered the minimum necessary to service electronic motor control: (1) a vacuum-tube voltmeter or a high-resistance volt-ohmmeter, and (2) several sizes of d-c ammeters.

Fig. 6-10. Checking wave shapes with the cathode-ray oscilloscope facilitates troubleshooting this electronic control panel and permits quick isolation of the faulty circuit or circuits.

Vacuum-tube Voltmeter

The commercial vacuum-tube voltmeter, because of its inherent flexibility, will help in finding both the simple and the more complex troubles that may arise. It may be used instead of a bell set to check circuits for correctness or for shorts or opens. It will measure the resistance of transformer or reactor windings as well as the resistance of any panel resistor or external resistor. The a-c voltage scales will measure a-c line voltage, anode transformer secondary voltage, a-c control voltage, and the various tube filament voltages. Because an extremely small amount of current flows through these instruments, they are ideal for measuring the d-c voltage throughout the low-power, high-resistance electronic control circuits which might be disturbed by low-resistance types of d-c meters. Vacuum-tube voltmeters may be used as well as conventional meters to measure motor-power circuit voltages.

FIG. 6–11. Electronic motor-control drive makes this drill press a very popular and versatile tool. Speed range is 25 to 1,750 rpm; it is used for drilling, tapping, fly cutting, etc.

For most electronic equipments, including those mentioned here, a voltmeter with a resistance of 20,000 ohms per volt will be just as suitable as a vacuum-tube voltmeter. Commercial forms of these instruments include a-c and d-c voltage scales as well as resistance scales.

The instruction books accompanying these instruments give detailed operating procedure.

Direct-current Ammeter

The d-c ammeters should be suitable for measuring the current in both the armature and the field circuits of the motor. The instruments should also be capable of reading any overload placed on the motor. An approximate figure of 4 amp per hp at 230 volts d-c will be satisfactory for determining armature ammeter sizes. Field currents will generally vary from about ½ amp for a 1-hp motor to about 3 amp at 20 hp.

Cathode-ray Oscilloscope

Although the cathode-ray oscilloscope is not essential for servicing electronic motor control, it will remove much of the fear of electronic equipment because it lets one see what is actually going on in the various circuits. Because it transforms what appears to be a static device into a very real piece of moving machinery, it is invaluable.

A slight modification is usually necessary to make commercial oscilloscopes suitable for seeing the d-c and the combination of d-c and a-c voltages that are present in motor-control circuits. To see these voltages in their true relations, it is necessary to apply them directly to the two vertical deflecting plates of the cathode-ray tube.

General Suggestions for Trouble Shooting

Because no description of trouble shooting could ever list completely all possible causes of trouble, it is important that a trouble shooter become somewhat familiar with the general causes of trouble, but more specifically with the methods of finding them. We shall use here an actual control circuit as an example, but the suggestions are not limited to this particular circuit. Rather, they attempt to show the correct approach, as almost any trouble becomes easy to find once the approach is recognized.

Methods

There are two general methods of locating a faulty device: (1) a mechanical approach in which all devices suspected are either checked or replaced, and (2) an analytical approach in which functions and the circuits that provide these functions are isolated and checked for trouble. Experience will show that the ideal method is a combination of the two.

Table V lists a number of troubles and their possible causes. Practically all may be found either by testing circuit components or by measuring voltages. A vacuum-tube voltmeter can be used to measure the resistance of all transformer and reactor windings, and all contactor and relay coils; to test capacitors for open and short circuits; to measure resistors; or to find short and open circuits in the panel wiring.

It is helpful to know all circuit constants and voltages in a specific equipment, but in the absence of more definite information the voltages and resistances included in the following paragraphs may be used as rough guides in testing circuits and components. A careful study of the following paragraphs will be of considerable help in finding trouble.

Anode Transformer and Control Voltages

Anode transformer secondary voltages from center tap to the anode connection of one of the tubes should be in the neighborhood of 200 to 400 volts, depending on the motor voltage and the number of power tubes used. There will be approximately 300 volts from the center tap to the anode on a two-tube rectifier with a 230-volt motor. A four-tube rectifier on a 230-volt motor will have approximately 200 volts from center tap to anode. The voltage from center tap to the anodes of all tubes in a particular rectifier should be approximately equal.

Alternating-current control voltages are usually 110 volts but may be any standard voltage. The a-c control circuit voltage often stamped on contactor coils will help determine correct control voltage.

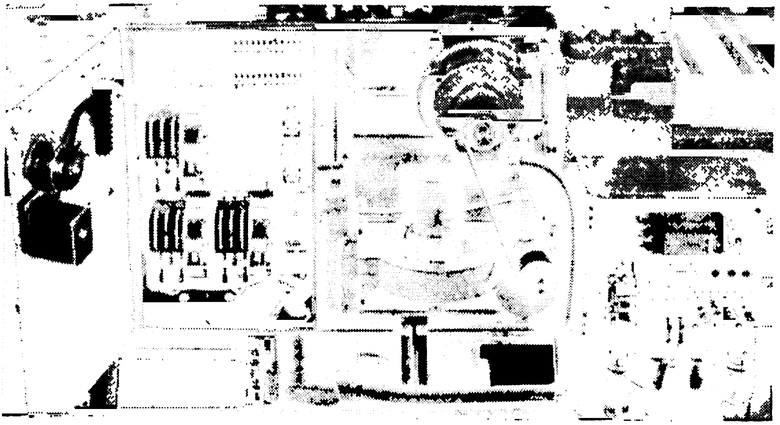


FIG. 6–12. Onsrud spar-milling machine equipped with electronic motor-control drive showing motor (center), a-c magnetic controller (left), and Thy-mo-trol panel (right). Motor is rated 2 hp and drives carriage feed.

The a-c scales of a vacuum-tube voltmeter will readily indicate both the anode and the control voltages.

Tube Voltages

Tube-type numbers often give some clue as to their operating voltage.

For example, the d-c voltage across a glow tube may be indicated by its type number. The tube GL-OD3/VR-150 should have approximately 150 volts across it; GL-OA3/VR-75 should have approximately 75 volts. These voltages can be read on the d-c scales of a vacuum-tube voltmeter.

The filament voltage of receiving-type vacuum tubes is generally indicated approximately by the first number in the type designation. A 6SN7-GT tube has a filament rating of 6.3 volts. A 25Z6 tube has a filament rating of 25 volts. A 117P7 tube has a filament rating of 117 volts. Although various tubes have filament voltages that cover a wide range, the tubes used in this type of equipment will usually be rated 6.3 volts.

Thyratron and phanotron power-tube filament ratings are almost always below 6 volts. Typical ratings are 1.25, 2.5, and 5.0 volts.

The low-voltage a-c scales on a vacuum-tube voltmeter can be used to measure filament voltage. Although the readings may not be extremely accurate, they may be used to determine whether the filament voltage is of the proper magnitude.

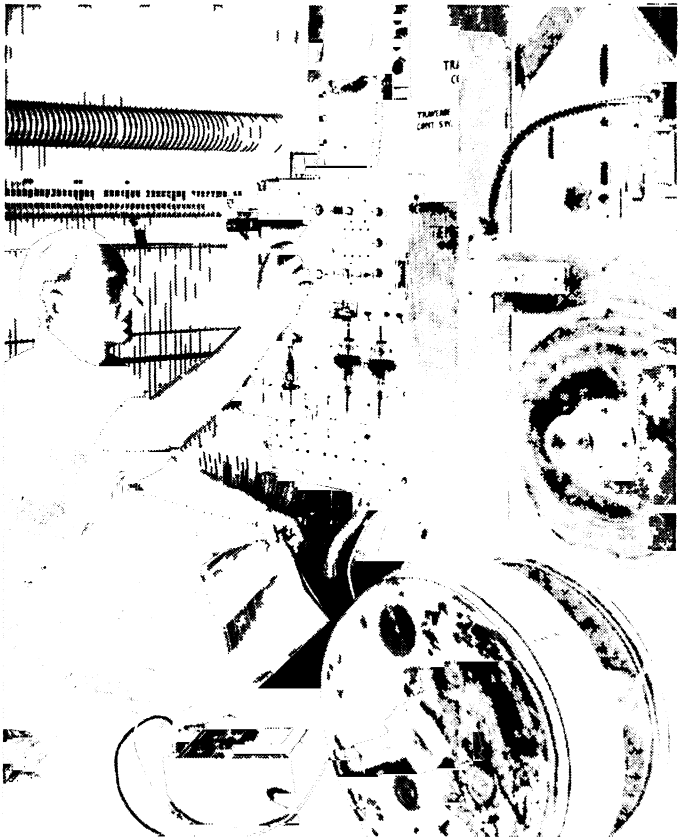


FIG 6-13 Final operating adjustments are being made here on a Thy-mo-trol drive applied to a wire-speed-control capstan in a wire-enameling process

Proper Method of Measuring Resistances

Most vacuum-tube voltmeters can be used to measure resistance Full-scale resistance readings usually range from 100 ohms or lower to 10 megohms or higher.

When measuring the resistance of a resistor, transformer winding, or capacitor, or even when checking for open or short circuits, one must be careful that the readings taken actually represent the resistance of the part being measured. Often parallel resistance paths will give readings that are entirely in error. For example, if the resistance of a filament transformer secondary is being measured, all tubes should be removed from their sockets; otherwise the resistance value read on the meter would be much lower than the resistance of the transformer winding itself. A resistor in parallel with a capacitor would indicate that the capacitor was faulty, when actually it might not be. Other examples could be shown.

If there is any doubt as to whether other resistance circuits are in parallel with a particular unit, all leads should be removed from one of the two terminals of the particular unit being measured. This will assure the proper resistance measurement.

Resistance Measurement of Transformer and Reactor Windings

The resistance of transformer windings is dependent on the size of the transformer and the voltage ratings of a particular winding. Large transformers have lower resistance windings than small transformers. High-voltage windings have higher resistance than low-voltage windings. All windings of anode power transformers should have a resistance *below* 10 ohms. Primary windings of thyratron filament transformers or filament transformers for the several control tubes should be *below* 100 ohms. Filament transformer secondary windings should be *below* 10 ohms. Small grid transformers, reactors, and saturable reactor windings should have resistances *below* 10,000 ohms. Other small control transformer resistances should be *under* 1,000 ohms.

Capacitor Measurement

Capacitors may be measured accurately with a capacitance bridge. For service work, however, where accuracy is not too important, shorted capacitors or capacitors with low leakage resistance can usually be located either by measuring the resistance of the capacitor with a vacuum-tube voltmeter or by a direct substitution of a known good one for a suspected faulty one.

Capacitors of 0.05 μf and smaller should have a resistance not lower than 10 megohms. Capacitors between 0.1 and 1.0 μf should have a resistance not lower than 5 megohms. Larger capacitors are generally used in circuits where a low leakage resistance may not cause faulty operation; even they should have resistances of at least 1 megohm. If there is any question about a particular capacitor, a good one should be measured for comparison.

Although a resistance measurement will not locate directly open-circuited capacitors, the resistance-measuring portion of a vacuum-tube voltmeter will indicate whether or not most capacitors are open. To make this test, the instrument should be connected to a high-reading resistance scale. It is important that no other circuits parallel the capacitor. If the meter swings up scale and then back at the instant the leads are touched to both capacitor terminals, the capacitor is OK. The amount of swing will be determined by the size of the capacitor and the resistance scale being used. Large capacitors will give a much greater swing than small ones. Very small capacitors (0.001 μf and smaller) cannot be tested in this manner because the meter swing will be too small to see. If this test is repeated, the capacitor terminals should be shorted between tests.

Electrolytic capacitors cannot be easily tested by resistance measurement because they may have a low leakage resistance, particularly if power has been off them for some time. The best test of these capacitors in the absence of a capacitance meter is to make a direct substitution of a good one.

Resistors

The resistance value of small carbon-type resistors is usually indicated by the colored bands around them. Some resistors have the body of one color, one end of another color, and a dot at the center, or a stripe around the center of another color. Other resistors have three stripes near one end. In the first type the sequence of colors is *body, end, dot,* or *stripes.* In the second type the sequence of colors is from the end to the center. In either case the colors have the same meaning. Figure 6-14 shows the various colors and the associated numbers.

The three colors can be combined to give the resistance value in the following way: The first color indicates the first number. The second color indicates the second number. The third color tells how many zeros to place after the first two numbers. The colors of brown (1), black (0), and orange (3), for example, indicate a resistor of 10,000 ohms.

Another color is sometimes added to tell how near the resistance value should be to that actually indicated by the other colors. A gold band indicates that it should be within 5 per cent, a silver band within 10 per cent, and no band indicates 20 per cent tolerance.

Resistors that are not color-coded usually have the value stamped somewhere on the unit.

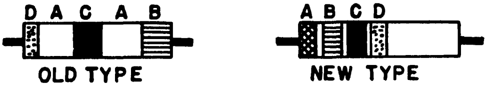
Interpretation of Diagrams

Any complete equipment diagram consists of two basic subdivisions: an elementary diagram and a wiring diagram.

Elementary or Schematic

An elementary or schematic diagram is made primarily to show in the simplest possible manner the electrical circuit for the entire equipment. Therefore no thought is given to the actual physical location of the various parts. This diagram is a great help in analyzing the various circuits to see how they operate and to locate possible causes of failure.

LARGE RESISTORS USED ON CONTROL PANELS USUALLY HAVE THE RATINGS PRINTED OR STAMPED ON THEM. SMALL RESISTORS OF TWO WATT SIZE AND BELOW ARE MARKED BY THE FOLLOWING COLOR CODE. RESISTOR VALUES ARE IN OHMS.



A - COLOR FOR 1ST. SIGNIFICANT FIGURE.
B - COLOR FOR 2ND. SIGNIFICANT FIGURE.
C - COLOR FOR NO OF CIPHERS OR MULTIPLIER.
D - GOLD OR SILVER INDICATES TOLERANCE, WHEN APPLIED.

COLOR	SIGNIFICANT FIGURE	MULTIPLYING VALUE
BLACK	0	1
BROWN	1	10
RED	2	100
ORANGE	3	1,000
YELLOW	4	10,000
GREEN	5	100,000
BLUE	6	1,000,000
VIOLET	7	10,000,000
GRAY	8	100,000,000
WHITE	9	1,000,000,000
GOLD	± 5% TOLERANCE	
SILVER	±10% TOLERANCE	
NO COLOR	±20% TOLERANCE	

EXAMPLES

RESISTORS

1.2	MEGOHMS	BROWN	(1)	RED	(2)	GREEN (x100,000)	GOLD (± 5%)
60,000	OHMS	BLUE	(6)	BLACK	(0)	ORANGE (x 1000)	SILVER (± 10%)
510	OHMS	GREEN	(5)	BROWN	(1)	BROWN (x 10)	---
3.5	OHMS	ORANGE	(3)	GREEN	(5)	GOLD (x 0.1)	GOLD (± 5%)

FIG. 6-14. RMA standard color code for small resistors.

Figure 6-15 shows a complete elementary diagram of a standard 2-hp, single-phase, nonreversing electronic motor control which provides control for both the armature and the shunt field of a d-c motor. In this stage it looks quite complicated. Part of this complexity is due to the number of different circuits involved. These will be broken down into individual simple circuits and discussed later. Aside from this apparent complexity, however, certain customs and practices result in unnecessary confusion unless one is able to interpret them.

Nomenclature

Usually there is not sufficient room on a diagram to describe completely all the various devices. On the drawing, therefore, each unit is given an abbreviated title which is explained in the nomenclature list. For example, *ASX* in Fig. 6-15 is listed in the nomenclature as "saturable reactor—armature circuit." Resistors and capacitors are numbered arbitrarily and are not generally given any one title. On the other hand, the adjustable resistors and potentiometers are usually given some title to help in identifying them.

Tube Designations

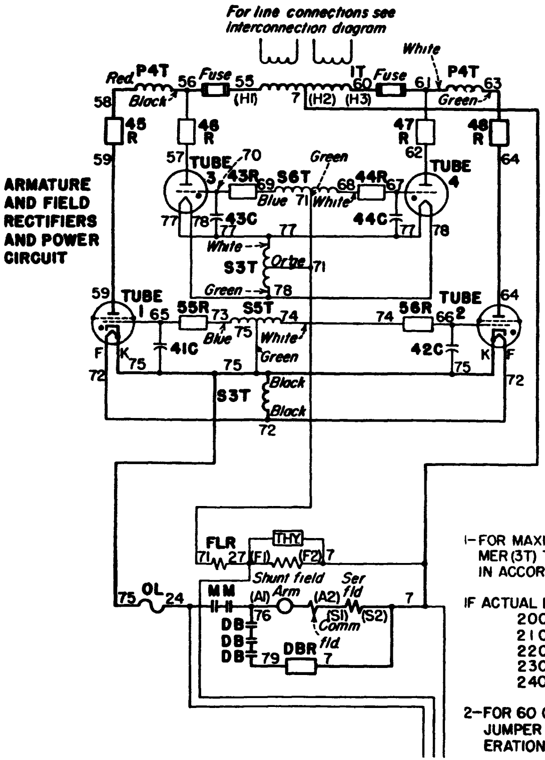
Sometimes tube-type numbers are located beside the tube symbol. In many cases, however, the tubes are numbered or lettered or, perhaps, the power tubes are numbered and the control tubes lettered.

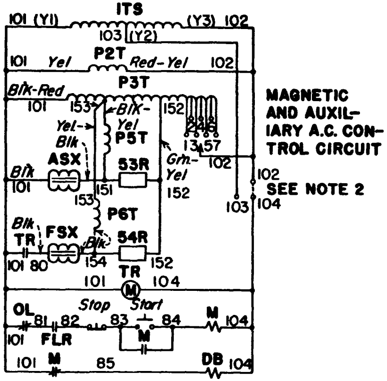
If you examine carefully the control-tube lettering in Fig. 6-15, you will notice that there are two tubes labeled—"Tube C," also two labeled "Tube D," "Tube E," and "Tube F," respectively. Tubes are labeled in this manner to show that both units, which bear the same letter, are actually enclosed in a single glass envelope. The two individual sets of tube elements however may be and actually are located in entirely separate parts of the complete circuit. This is done for the reason that from a circuit operation standpoint and for clarity in reading the diagram, the procedure is simplified by separating the two tube sections as shown.

Transformers

At first glance, transformer and reactor terminology and connections may also seem queer, but here, as in the case of tubes, there is a definite system which is simple when it is understood.

One transformer may have a number of different windings, each of which is used in a different part of the circuit. In such a case, it is much simpler, from a circuit standpoint, to show the windings in the circuits where they are used than it would be to have all the leads running to a common location. In locating windings at various points in this manner, however, it is important to be able to recognize which windings are on the same transformer. Therefore, an identification system must be used.





NOMENCLATURE

ASX--	SATURABLE REACTOR-ARM CIRCUIT
DB---	DYNAMIC BRAKING CONTACTOR
FLR--	FIELD LOSS RELAY
FSX--	SATURABLE REACTOR-FIELD CIRCUIT
INC--	INCREASE
M----	LINE CONTACTOR
OL---	OVERLOAD RELAY
SW---	SWITCH
IT----	ANODE TRANSFORMER
2T, 3T-	FILAMENT TRANSFORMERS
4T----	CURRENT TRANSFORMER
5T, 6T-	GRID TRANSFORMERS
THY--	THYRITE RESISTOR
TR---	THYRATRON CATHODE PROTECT RELAY
IVR--	CURRENT LIMIT ADJUSTMENT
2VR--	IR COMPENSATION ADJUSTMENT
3VR--	MAXIMUM SPEED ADJUSTMENT
4VR--	ARM VOLT ADJ (FACTORY ADJUSTMENTS)
5VR--	FIELD VOLTAGE ADJUSTMENT
6VR--	MINIMUM SPEED ADJUSTMENT
7VR--	SPEED CONTROL-ARMATURE RANGE
8VR--	SPEED CONTROL-FIELD RANGE

PURCHASER'S NOTES

1-FOR MAXIMUM TUBE LIFE, SET TAP ON TRANSFORMER (3T) TO CORRESPOND TO ACTUAL LINE VOLTAGE IN ACCORDANCE WITH THE FOLLOWING TABLE

IF ACTUAL LINE VOLTAGE IS	SET TAP ON
200 OR 400	2
210 OR 420	3
220 OR 440	4
230 OR 460	5
240 OR 480	6

2-FOR 60 CYCLE OPERATION, PURCHASER SHOULD JUMPER POINTS 102 AND 104 FOR 50 CYCLE, OPERATION, JUMPER POINTS 103 AND 104

TUBE TYPES AND FUNCTIONS

TUBES 1 AND 2	FG172	THYRATRONS FOR ARM CONTROL
TUBES 3 AND 4	GL-393A	THYRATRONS FOR FIELD CONTROL
TUBE A	6X5GT	RECT FOR DC CONTROL POWER
B	GL75-30	VOLTAGE REG FOR DC CONTROL
C	6SN7GT	AMPLIF FOR FIELD AND ARM CONTROL
D	6SN7GT	AMPLIF FOR FIELD AND ARM CONTROL
E	6SN7GT	AMPLIF FOR CURRENT LIMIT
F	7K7	AMPLIF FOR VOLT LIMIT AND RECT FOR CURRENT LIMIT AND IR COMP
G	GL75-30	VOLTAGE REG FOR DC CONTROL
H	6SN7GT	AMPLIFIER FOR PRECONDITIONING

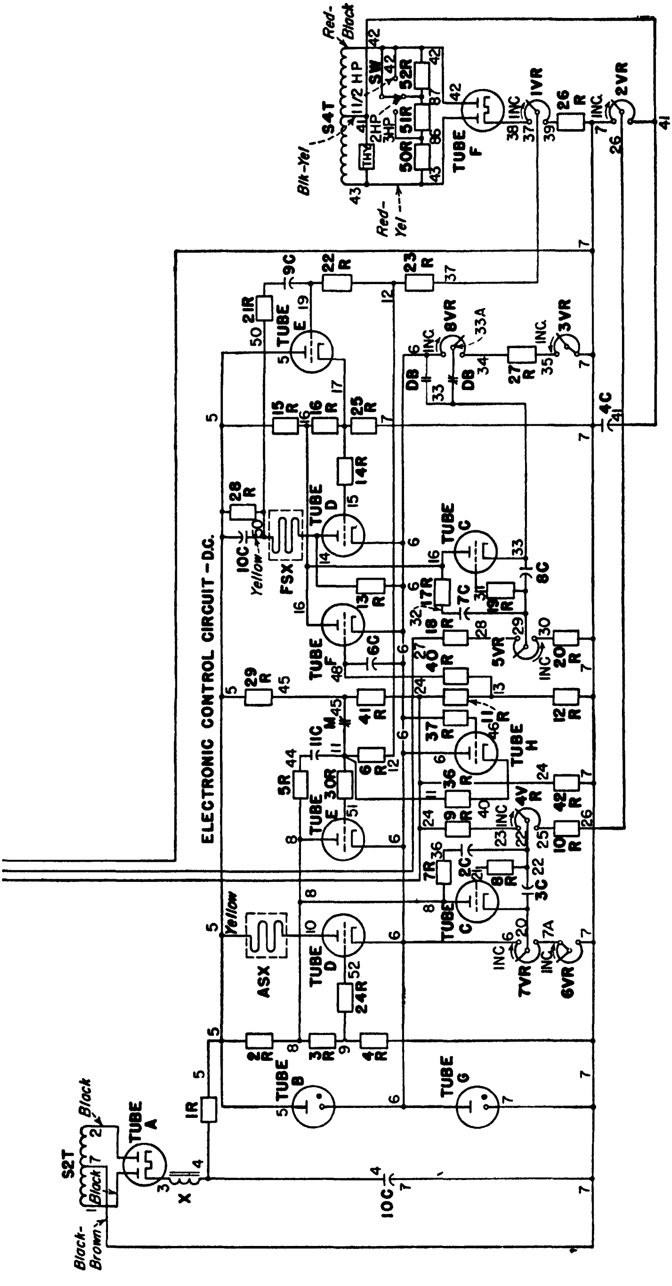


FIG. 6-15. Elementary wiring diagram showing circuit elements in a simplified rearrangement for easy reading. Note that the d-c control circuits are arranged so that the points of higher positive potential are positioned higher on the drawing. Positions are approximately relative to their operating potentials.

For an example, let us take transformer *3T*, listed in the nomenclature as a filament transformer. The primary of this transformer, connected between lines 101 and 102, is labeled *P3T*. The secondaries are both labeled *S3T* and are used to heat the filaments of the armature and field power tubes, respectively. *S3T* between lines 72 and 75 supply the armature-tube filaments while *S3T* between lines 77 and 78 supply the field-tube filaments.

The saturable reactors have two windings: an a-c winding and a d-c winding. The d-c windings are located in the d-c control circuit, while the a-c windings are located in the a-c control circuits. Both windings of any reactor have the same identification (*ASX* or *FSX*), indicating that they are located on the same core. The *A* suffix indicates that it is an armature circuit saturable reactor and the *F*, a field circuit saturable reactor.

Voltage Levels

Although a-c power and control circuits are usually arranged to be most convenient, d-c control circuits are often arranged as voltage-level-indicating diagrams. With a diagram drawn this way, one can tell at a glance the approximate magnitude as well as the polarity of a voltage between two points.

In looking at the d-c electronic control circuit of Fig. 6-15, which is drawn to indicate voltage levels, it is apparent that line 6 is of a higher positive potential than line 7; that line 5 is higher than line 6, and so on. Diagrams drawn in this manner are really a great help in analyzing circuits of this type.

Wiring Diagrams

Although the elementary diagram is essential in analyzing the circuit and any faults that may develop, its counterpart, the wiring diagram, is just as essential in trying to find the location on the panel of any suspected unit. The wiring diagram shows as nearly as possible the actual physical position of all devices. Since the elementary diagram is intended to show the operation of the entire system, it must include not only the equipment mounted on the panel but also all the external equipment, such as the anode transformer and the motor. The wiring diagram, though, may, for convenience, be broken into several different sections.

The wiring diagram for the equipment shown in the elementary diagram in Fig. 6-15 is divided into three parts: the interconnection diagram (Fig. 6-7), the main panel diagram (Fig. 6-16), and the control unit diagram (Fig. 6-19). The interconnection diagram is of help in checking troubles external to the panel, as well as in making the initial installation. The main panel diagram and the control unit diagram show the location of the components on the respective units.

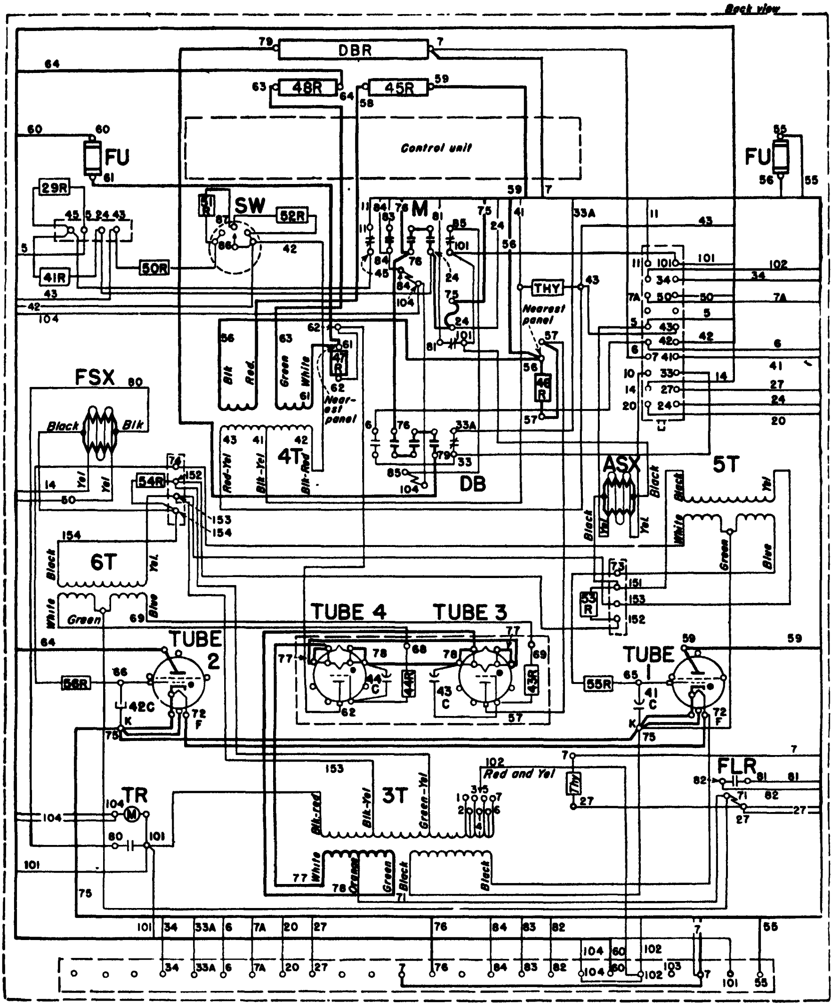


FIG. 6–16. Panel wiring diagram of an electronic motor control. Circuit elements are in their approximate position and can be compared with the panel photograph shown in Fig. 6–17.

Location of Components

Figure 6-16 shows the main panel wiring diagram, marked "back view." Let us compare this diagram with the photograph of the back view of the panel shown in Fig. 6-17. At the bottom of both

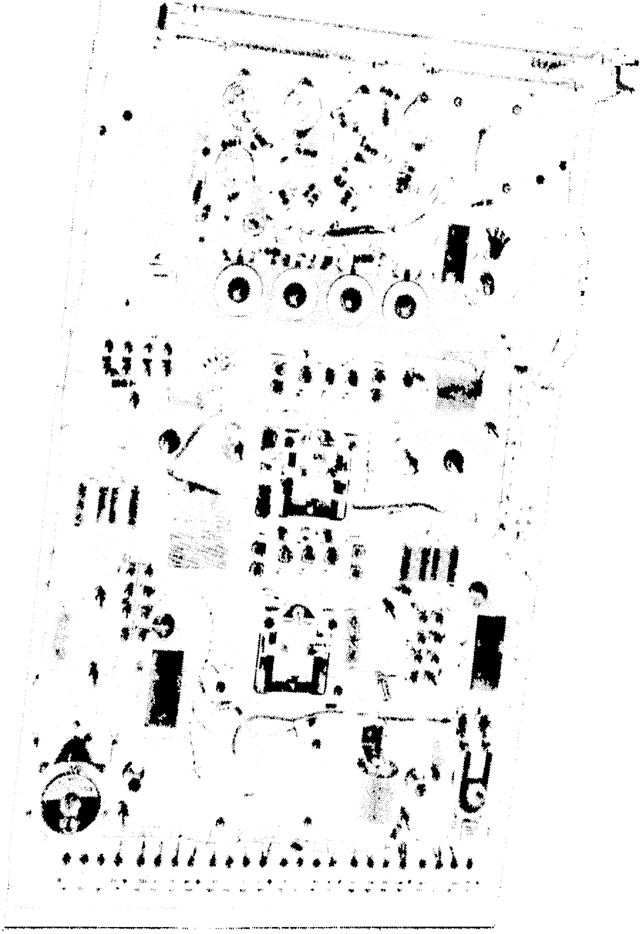


Fig. 6–17 Panel wiring of Thy-mo-trol armature and field control, nonreversing, 2-hp, 230-volt d-c motor. Compare the component parts with the panel wiring diagram shown in Fig. 6–16.

figures is the terminal board for outgoing connections. Just above the terminal board, from left to right, are the cathode protective timing relay (*TR*); the thyratron filament transformer (*3T*); the field-loss relay (*FLR*). The wiring diagram shows the thyrite discharge resistor and tubes 2, 4, 3, and 1 above these units, but these tubes are mounted on the front of the panel and do not show in the back-view photograph.

The photograph shows the field saturable reactor *FSX* several inches above *TR;* the current transformer 4*T* to the right of *FSX;* and grid transformer 6*T* below *FSX*. The wiring diagram does not show them in exactly the same position, but they are sufficiently close for identification. The terminal board located between these three units can be seen on both the photograph and the diagram. A further comparison of the diagram and the photograph will show the other transformers, resistors, capacitors, and contactors mounted on the back of the panel. The fuses are mounted on the front and so do not show on the photograph.

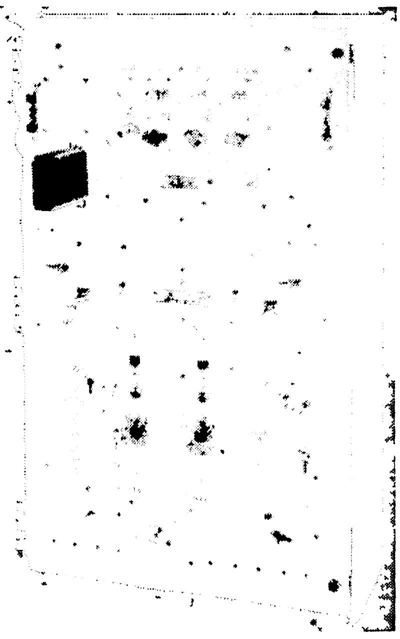


FIG. 6-18. Front of Thy-mo-trol panel showing armature and field thyratron tubes, constant-voltage glow tubes, rectifiers, and other control tubes with relay and filament transformer.

Control Unit

Near the top of the panel wiring diagram (Fig. 6-16) is a dotted rectangle which corresponds to the control unit shown in the photograph. Since the control unit is a separate assembly and can be removed from the main panel by taking out some screws and disconnecting a plug, the wiring diagram is made as a separate drawing. This is shown in Fig. 6-19.

If Fig. 6-19 is compared with the panel photograph (Fig. 6-17), the various tube sockets, adjusting potentiometers, and the filament transformer can easily be identified. It is a little more difficult to locate the small resistors, but their position may be determined by tracing the connections to the tube sockets, capacitors, potentiometers, or terminal blocks as the case may be.

Wiring Diagram Limitations and General Practices

Because a wiring diagram must show on one side of a single sheet of paper not only the material that is located on both sides of a panel, but also the device terminals which may be directly in back of others rather than above or below them, some system must be used that will make a diagram understandable. Where device terminals are located directly behind others, the practice is to show the one nearest the panel on top and the one away from the panel below.

Tubes 3 and 4 are located on a shelf in front of the panel and can be seen in the front view photograph, Fig. 6-18. In this case, again, the terminals nearest the panel are shown at the top and the terminals away from the panel are shown below.

Tube Connections

Where all tube connections come through the socket, the tube symbol is easily interpreted. The locating pin on octal-type tubes is shown on the wiring diagram. Tube element numbers are as shown in Fig. 6-19, numbering clockwise from the locating pin. The index mark on other than octal tubes is between the two filament connections.

If connections are brought out through the top or side of the tube, or if the tube has no socket at all, a certain amount of imagination must be used in interpreting the tube symbol. Figure 6-16 shows both types of tubes. The symbols as shown in Fig. 6-19, however, look much the same as those in the control unit. Wherever connections are actually made through the socket, the dotted connections appear directly on the circle enclosing the tube symbol. If the connections are made at caps or studs coming out the side or top of a tube, the connection will look like a small rectangle. For example, see Fig. 6-16, leads 66, 62, 57, and 65 on tubes 2, 4, 3, and 1, respectively. These are shown as terminals on the side of tubes 1 and 2, and caps at the top of tubes 3 and 4 in Fig. 6-18.

Where the tube itself has leads, as shown on tubes 1 and 2 in Fig. 6-18, the symbol is shown with the connection dot beyond the circle enclosing the tube symbol. This is shown in Fig. 6-16, leads 64, 59, 75, and 72*F* on tubes 1 and 2.

Transformer Symbols and Marking

Transformer leads are almost always colored or marked in some manner for identification. These markings are also shown on the diagram. If the leads are numbered, it is important to bear in mind that these numbers may not agree with the panel numbering.

Trouble in Initial Installation

The apparent complexity of electronic circuits often gives the trouble shooter a few trepid moments when he has finally isolated a specific trouble to the electronic control system. Actually the trouble

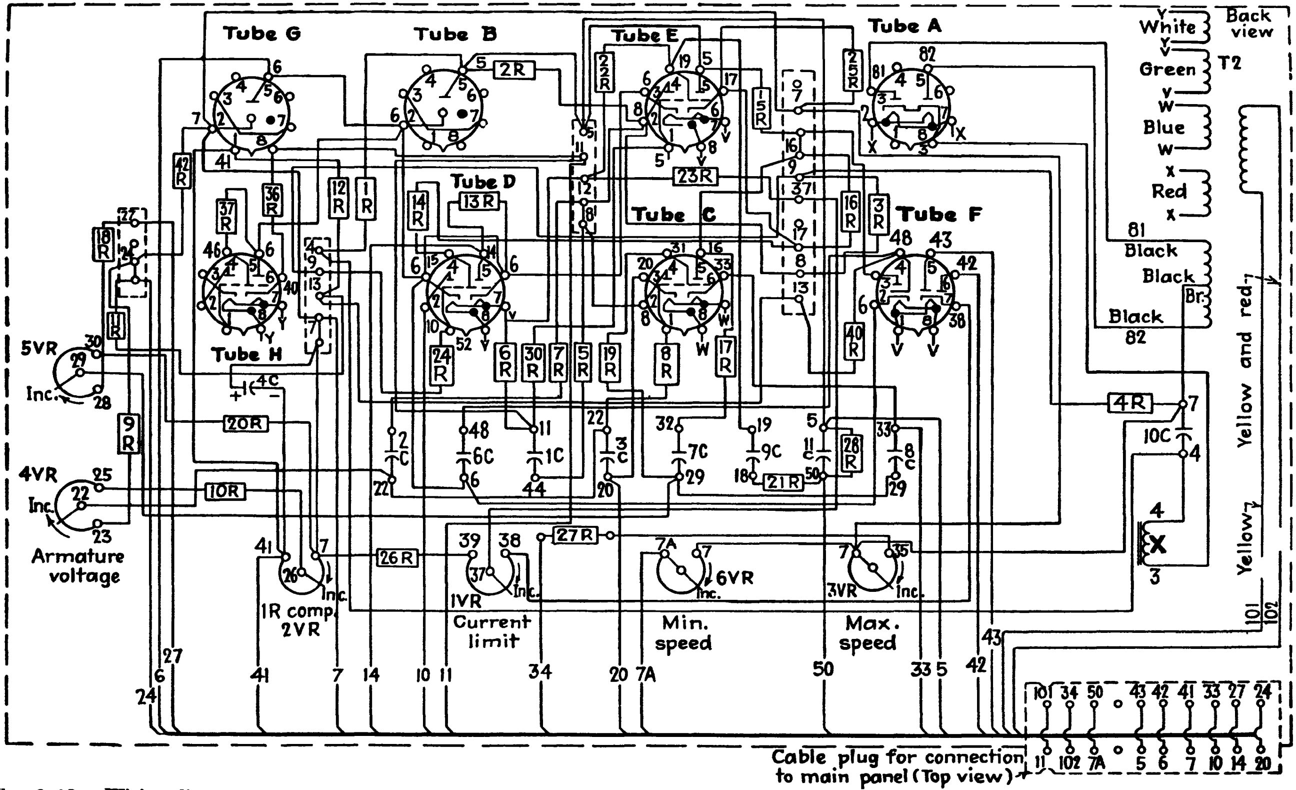


FIG. 6–19. Wiring diagram of control circuits mounted on a subpanel on the main motor-control panel. Bases of tube sockets, potentiometers, resistors, capacitors, etc., can be seen in Fig. 6–17. Front of subpanel with tubes, relay, and transformer are shown in Fig. 6–18,

may be as simple as a blown fuse or a defective tube. If a person familiarizes himself with the material pointed out in the previous portion of this chapter, he will feel relatively at home with an electronic panel and diagram. With that as general background, let us go ahead with an analysis of some of the troubles that may arise in servicing electronic motor control, and the methods of finding them. The same general approach may be used in trouble-shooting any type of control employing electronic circuits.

If a motor drive will not operate properly when it is first installed, it is probable that some mistake has been made in setting up the equipment. Perhaps the interconnecting wires have not all been connected according to the diagram, or one or more tubes may be in the wrong sockets. At this early stage one should not expect to find trouble in the panel itself, unless it has been damaged in shipment or through mishandling. If there is any indication of panel damage, all parts should be inspected to see if there are any broken parts or leads or shorted terminals.

There may be exceptional cases where an equipment will not perform properly when all installation work has been done correctly. The various approaches discussed later will be of help in these cases.

Common Troubles

Looking first for simple troubles (which are most likely to happen) will often save time and prevent confusion in looking for more complex troubles that do not exist.

Overload Relay

If the motor suddenly stops, the overload relay, which protects the motor against instantaneous or maintained overloads, is one of the first things to suspect. After the few seconds required for most relays to reset, the motor may be restarted by merely pushing the START button if the relay is of the automatic-reset type; or by first manually resetting the overload relay and then pushing the START button if the relay is manual reset.

An occasional tripping of the overload relay may not indicate any other trouble. The cause of continual tripping, however, should be investigated because it may be a sign of tight machine bearings or a badly overloaded motor. If the room temperature is too high, the relay is likely to trip at a lower motor load than in a colder room. A defective armature rectifier tube or a blown fuse might also cause the overload relay to trip.

Fuses

If the motor will not run and none of the tubes are lighted, the chances are good that there is a blown fuse in the primary of the anode transformer. If the tubes are lighted, however, the trouble is elsewhere.

Frozen machine bearings may stall a motor and blow the fuses in the anode circuits of the thyratron tubes. A frozen bearing may easily be found on small motor drives by manually rotating the shaft. (*An important precaution here is to open the line switch before trying to rotate the motor by hand.*)

A short circuit in the armature or field circuit, a defective armature rectifier tube, or a fault in the current-limit circuit may also cause anode fuses to blow. If a fuse is blown, the thyratron tubes connected to its circuit will not show the characteristic glow of a gas-filled tube.

Tubes

There are several ways in which tubes can fail: open filaments, loose or shorted elements, lack of emission. A tube with an open filament is easily found because it will fail to light and no red glow will be seen in the envelope.

Tubes with loose or shorted elements are more difficult to find because the trouble is not apparent from the outside. Although the performance of the equipment will indicate this type of failure, a sure check is the substitution of a good tube. Sometimes tube elements are intermittently loosed or shorted. Intermittently defective tubes may be found by tapping the tube lightly with a block of wood or the head of a screw driver and observing the effect on the control performance.

A gradual loss of emission from the tube cathode as the tube ages will affect the performance of the power or control rectifier tubes or any others carrying fairly large currents.

In all cases the best check on any tube is its operation in a specific equipment. The best check on a tube's performance is a direct comparison with the performance of a known good tube.

Each tube in an electronic equipment, generally speaking, has one specific function to perform. Figure 6-15 is the elementary diagram of the electronic motor control. On the right is a list of tubes used in this particular equipment and the functions they perform. The following is an expansion of the functions and the effect of various tube failures. Although these functions will vary with different equipments, the examples indicate how easy it is to find troubles caused by defective tubes.

Tubes 1 and 2. Thyratrons for Armature Control

When thyratron tubes are operating properly, a blue glow, indicating ionization of the gas, can be seen between the tube elements. Since the armature thyratron tubes supply all the power to the motor armature, the motor cannot run unless they are working. Although the motor will operate with only one good tube, it will not respond so rapidly as it should, nor will it run so fast as it should at full load. Operation with only one tube increases the heating value of the armature current and is therefore likely to trip the overload relay or blow the fuse *in the circuit of the good tube.* If such trouble is suspected, substitute a good tube in the proper socket before replacing fuse or resetting relay.

Tubes 3 and 4. Thyratrons for Field Control

The field thyratrons (or phanotrons, if used) should, when operating properly, have the same blue glow as the armature thyratrons. If either of these tubes fails, there will not be sufficient current flowing to pick up relay *FLR*, which is shown in Fig. 6-15, in series with the motor field. With relay *FLR* deenergized, the motor-line contactor will not pick up and the motor will not run (see start-button control circuit).

Tube A. Rectifier for Direct-current Control Power

This tube supplies all d-c control power for the various control functions. If this tube fails or if its emission is low, the motor will not run.

Tubes B and G. Voltage Regulators for Direct-current Control

Voltage-regulator tubes are gas-filled and show a definite glow of color when operating properly. Although an external fault could cause a tube not to glow, a dark tube might be defective.

Tube C. Amplifier for Field and Armature Control

The two individual sections of this tube are in the armature and field comparison circuits, respectively. If this tube fails, the speed control will not have much effect on the motor speed.

Tube D. Amplifier for Field and Armature Control

The two sections of this tube amplify and invert the phase of the signals from tube *C*. A failure of this tube will stop the motor.

Tube *E*. Amplifier for Current Limit

This tube controls both the armature and the field voltage during acceleration or overload on the motor. If it fails, the motor will start with high armature current and torque peaks. Repetitive starting with this tube defective may blow the anode fuses.

Tube *F*. Amplifier for Voltage Limit, and Rectifier for Current Limit and IR Compensation

A failure of this tube will appear similar to a failure of tube *E*. At low speeds, however, the motor will not have much torque because the *IR* drop compensation, which is effective primarily at low speeds, is a function of tube *F*.

Tube *H*. Amplifier for Preconditioning

The effect of the loss of this tube is similar to the failure of tube *E*, but will not result in so severe current peaks as if tube *E* had failed.

Other Possibilities

Occasionally failure may occur in some of the panel components. Sometimes these are readily apparent. For example, a filament transformer may develop an internal short circuit which will result in overheating. Smoke from the transformer will "give this away." A rectifier tube socket or other socket with fairly high voltage across its terminals may flash over and carbonize the insulation between terminals. This can be seen by a black path between terminals, which will glow and smoke when power is on.

Because transformer, reactor, and resistor overheating may be caused by other troubles, such as a short-circuited capacitor or shorted terminals, it is well to test the associated circuits and correct any other defects before applying power again; otherwise, the replacement may burn up again.

A defective timing relay, dirty or broken relay contact tips, broken wires, or any other obvious troubles should also be considered as possible causes of trouble.

If the panel is in a very hot location, the thyratron tubes may misfire and the motor performance will be erratic. If the location is too cold on the other hand, the tubes may not fire at all and consequently the motor may not run. The temperature requirements of all tubes are not the same; therefore, consult the instruction book covering a specific equipment for any temperature limitations.

Circuit Analysis

Because practically all troubles in electronic motor control can be found without making a detailed panel circuit study, this study should be considered only as a last resort. In making a circuit study it is not necessary to jump right into the middle of the panel diagram, because the entire circuit can be broken into several simple circuits, which can be readily analyzed. As mentioned before, each tube has a function to perform. Likewise each circuit has a function to perform and the circuits may be divided in accordance with their functions. For example, Fig. 6-15 shows how the elementary diagram can be divided into three major divisions: (1) armature and field rectifiers and power circuit, (2) magnetic and auxiliary control circuit, (3) electronic control circuit.

Armature and Field Rectifiers and Power Circuit

Although the armature and field rectifiers, which are shown in Fig. 6-20, are dependent upon the other circuits for some phases of their operation, they may be considered as a complete circuit. Because all motor power passes through these circuits, we should start any circuit study here. One must be careful not to take anything for granted in this study because it is quite possible that a very obvious trouble may easily be overlooked.

Field Rectifier

To simplify these circuits still further, let us consider for the moment the field rectifier alone. The field-rectifier circuit consists of the anode transformer, anode fuses, surge resistors, 46*R* and 47*R*, tubes 3 and 4, grid transformer 6*T*, filament transformer 3*T*, and grid resistors and capacitors 43*R* and 44*R*, and 43*C* and 44*C*, respectively. This much is the rectifier proper. The load circuit, which consists of the field-loss relay and the motor shunt field with thyrite discharge resistor, is, however, equally important.

No Voltage

If the filaments of tubes 3 and 4 are lighted, we can be sure that there is *primary* power on the anode transformer and that the filament transformer 3*T* is good. If the field-loss relay will not close, a systematic check of voltages should be made. Direct-current voltage at the motor field terminals with no current flowing would seem to indicate an open motor field. The presence of voltage between points 7 (−) and 71 (+) with no voltage across the shunt field indicates an "open" coil in the field-loss relay.

If there is no d-c voltage between points 71 and 7, the a-c voltage between point 7 and points 55, 56, 57, 60, 61, and 62, respectively,

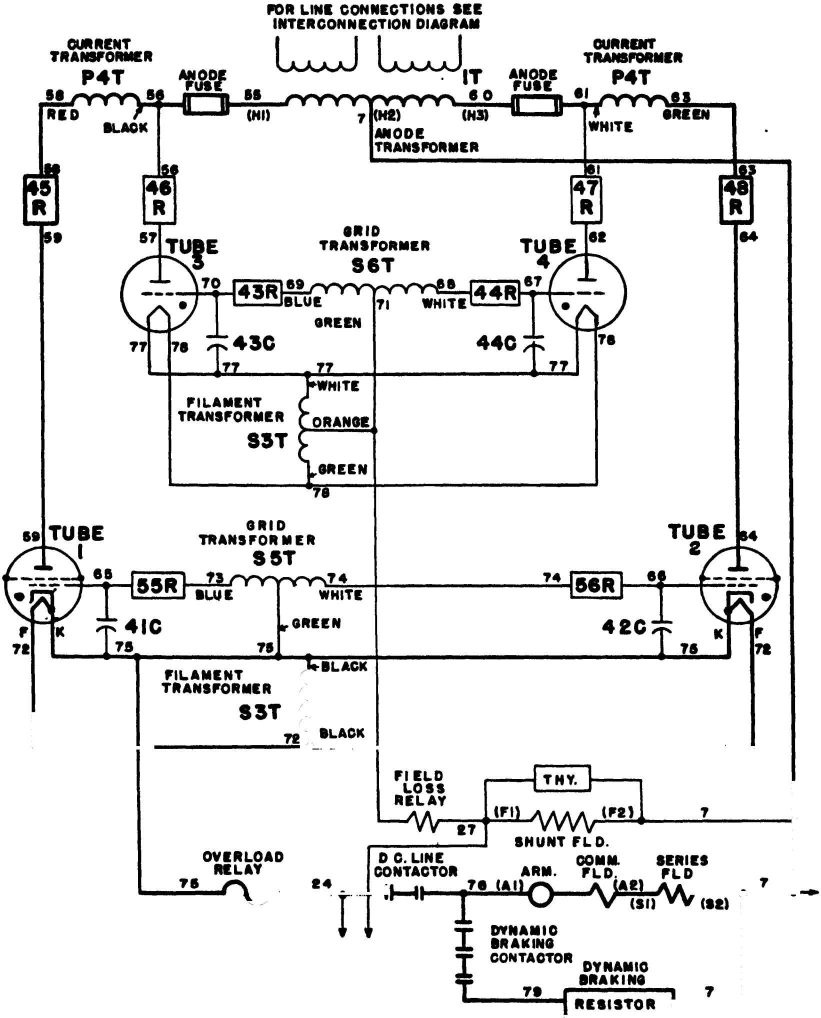


FIG. 6-20. Armature and field rectifiers, power circuits, and a-c control of elementary diagram shown in Fig. 6-15.

should be measured. Perhaps there is a broken transformer lead or a defective fuse or resistor. With approximately 300 volts between terminals 7-57 and 7-62, respectively, and yet no d-c output, the trouble must be either in the tubes or in the grid-firing circuits ahead of grid transformer 6*T*.

Except for broken connections or troubles ahead of transformer *6T*, all causes of lack of voltage have been covered.

Voltage without Control

Since the grid circuit is responsible for the rectifier control, a failure of any of the grid-circuit components could cause a loss of control over the d-c output voltage to the motor field. The resistance of resistors *43R* and *44R*, capacitors *43C* and *44C*, and the secondary winding of grid transformer *6T*, should all be measured to be sure they fall within the limits given previously in this chapter. If these components are found to be good and no loose connections are apparent then the trouble is probably ahead of the grid transformer.

Armature Rectifier

A further study of Fig. 6-20 will show that, although the numbering of components is different, the armature rectifier circuit is practically identical with that of the field rectifier. The only real differences between the two are the current transformer windings *4T* in the anode circuits and the load circuit which consists of an overload relay, a d-c line contactor, and the motor armature circuit with its series and commutating fields and its dynamic braking resistor and contactor.

To the causes for no voltage (given under "Field rectifier") can be added an open current-transformer winding and open contacts or broken connections in the armature circuit. The causes for lack of voltage control (through faulty grid-circuit operation) are the same as in the field rectifier.

Magnetic and Auxiliary Alternating-current Control Circuits

The magnetic and auxiliary a-c control circuits may also be considered as a separate part of the entire circuit, although, as in the case of the rectifier, the operation is somewhat dependent on other circuits.

Filament transformers *2T* and *3T* as well as the phase-shifting bridges, the timing relay, and the other magnetic control devices receive all power from an auxiliary 110-volt control winding on the main anode power transformer. An open circuit in the power transformer will prevent operation of any of the control circuits.

Phase-shifting Bridge

The a-c phase-shifting bridge is probably the only part of the a-c control circuit that needs any explanation. Figure 6-21 shows the grid-controlled field rectifier and its phase-shifting bridge which is used to control the firing point of the tubes. When power is applied to the filament transformer primary, the a-c voltage between points 101-153 should be approximately the same as the voltage between points 152-153.

If all rectifier components have been tested, in accordance with the section on "Rectifiers," and found to be good, yet there is still no output voltage, the phase-shift circuit may be responsible. An open timing relay contact or an open a-c winding in the saturable reactor *FSX* could cause this trouble. If no fault has been found thus far, the d-c winding of the saturable reactor may be to blame. If the resistance of this winding is over 5,000 ohms, the unit is probably defective and should be replaced.

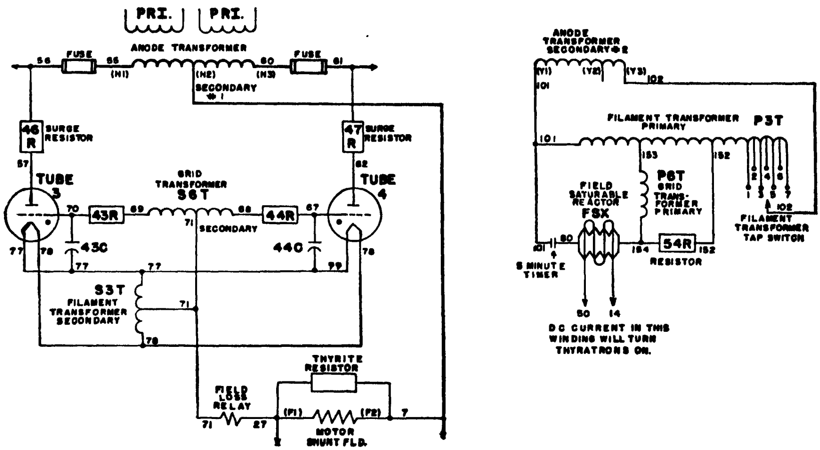


FIG. 6-21. Grid-controlled field rectifier with phase-shifting bridge.

If resistor 54*R* or the primary of transformer 6*T* (*P*6*T*) is open or if there is no voltage at primary terminal 101, 152, or 153 on filament transformer 3*T*, there will be voltage output from the rectifier, but it will not be controlled by the electronic control circuit.

The operation of the armature rectifier phase-shifting bridge is the same as just described for the field, and is subject to the same possible troubles.

All circuit components in the armature and field rectifiers and power circuits, as well as the a-c control circuits and phase-shifting bridge, are located on the main panel. The main panel wiring diagram is shown in Fig. 6-16.

Direct-current Control Power Circuit

Although the electronic circuits that control the armature and field rectifiers and provide most of the special functions may appear to be the most complicated part of the entire equipment, experience will show that, with the exception of the tubes, trouble is least likely to occur here.

In all the following discussions it is assumed that all tubes are satisfactory.

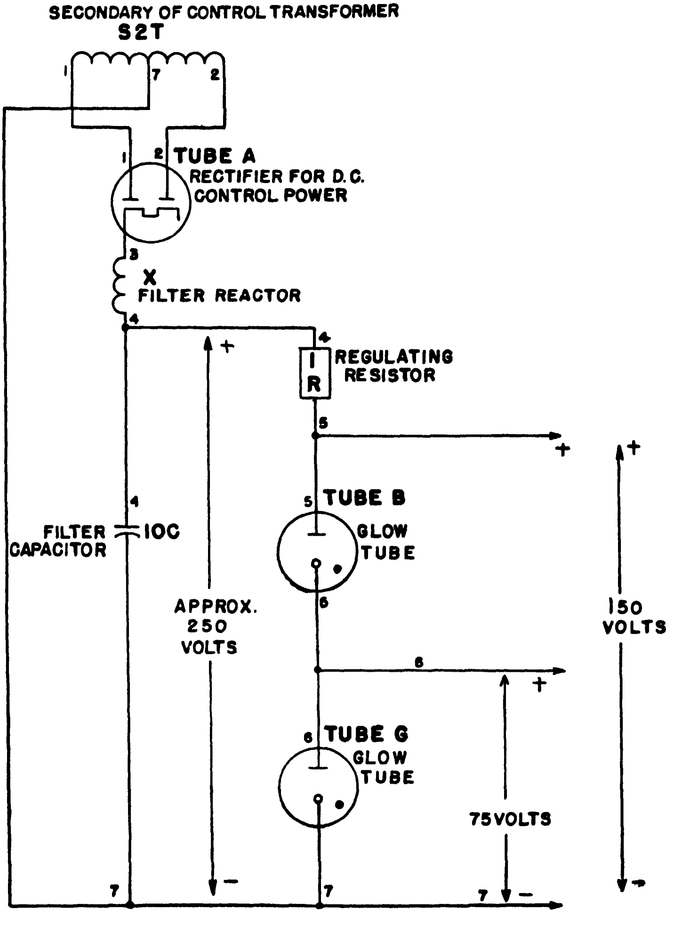


Fig. 6-22. Direct-current-control power circuit.

All control of both the armature and field rectifiers is accomplished through the d-c windings of the two saturable reactors *ASX* and *FSX*. Direct-current flowing in the d-c windings of the saturable reactors will shift the thyratron rectifier grids to produce an output voltage. There will consequently be no output from the thyratron rectifier if there is no current flowing in the d-c windings.

Figure 6-22 shows the circuit of the d-c control power rectifier which supplies all direct-current for operating not only the saturable reactors, but also the vacuum-tube circuits leading to the saturable reactors. This figure shows the approximate voltage that will be present when the rectifier is working properly.

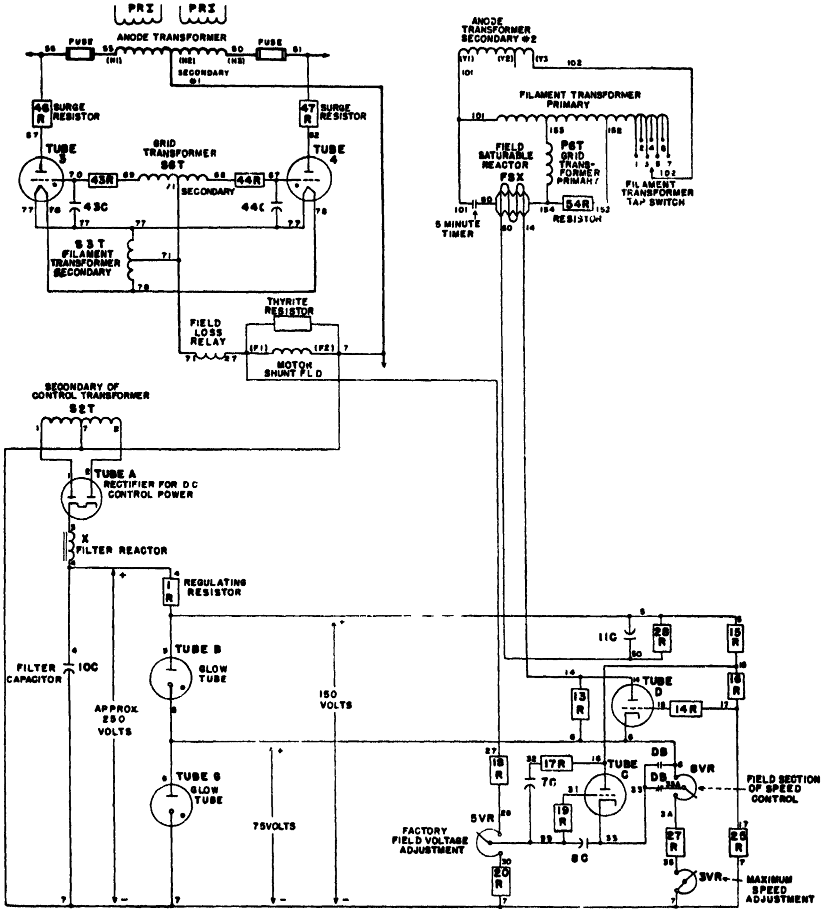


FIG. 6–23. Field rectifier and voltage control circuit.

Although voltmeter measurement is the most satisfactory method of checking this circuit, the two tubes (*B* and *G*) can, in a sense, be used as voltmeters. If both *B* and *G* glow, it is likely that the proper voltage is across lines 5, 6, and 7. A short circuit across lines 6 and 7 would prevent tube *G* from glowing and would overload both tubes *A* and *B*, as well as resistor 1*R*, filter reactor *X*, and transformer 2*T*. A short circuit across lines 5 and 6 would cause tube *B* to go out, while a short across lines 5 and 7 would cause both B and G to go out. Any of these short circuits is likely to cause damage to the other tubes and components.

Although it is possible that short circuits may develop in the internal panel wiring, it is likely that the ones just described might be in the outgoing panel leads. If so, they can be isolated by removing the external leads at the panel terminal board.

Resistance and Voltage Measurements

Possible internal troubles are an open resistor $1R$, or reactor X; a shorted capacitor $10C$ or an open winding on transformer $2T$. The resistance of these parts should be measured with power off.

Another approach is to measure voltages with power on. Direct-current measurements can be taken between point 7 (−) and points 6, 5, 4, and 3, (all +), respectively, to determine short or open circuits. If the filament of tube A is lighted but there is no voltage from 3–7, the a-c voltage 7–1 and 7–2 should be measured. Both voltages should be approximately 300 volts. An open transformer $2T$ would be indicated if tube A did not light or if there were no a-c voltage output between 1–2.

Field Regulating Circuit

Figure 6-23 shows how the various circuits fit together to give control of the motor field voltage. The rectifier and the a-c control circuits at the top of the figure have already been discussed. Let us assume that these circuits, as well as the d-c control circuit, just discussed (shown at lower left of Fig. 6-23) have all been found satisfactory. The field regulating circuit shown at lower right is almost all that is left to cause trouble in the field circuit.

Method of Isolating Circuit Being Studied

Figure 6-15 shows the entire elementary diagram. Although Fig. 6-23 shows the principal field control circuits, a comparison of the two diagrams will show that tubes E and F, which can affect the grid voltage of tube D, are not shown in Fig. 6-23. To be sure that the circuits associated with tubes E and F do not bother our thinking, let us remove these tubes from the panel. Now we know that we are considering only that part of the diagram shown in Fig. 6-23.

No Field Voltage

Although the d-c winding of FSX may be good, current will not flow through it if there is an "open" in any part of the circuit between lines 5 and 6. One of the leads on resistor 28*R* could be broken, or the resistor itself might be open. Broken leads or loose connections at the tube socket, points 6 or 14, would prevent current from flowing.

We know that tube *D* is good, but if its grid, point 15, is too far negative the tube will not conduct. Broken leads on resistors 15*R* or 16*R*, or open resistors would prevent tube *D* from carrying any current. A short circuit between points 16 and 7, or 17 and 7, would also make point 15 too far negative. Also, if tube *C* is conducting too much current, tube *D* would be off. Removing tube *C* from the panel will determine whether the trouble is in the circuits of tubes *C* or *D*.

Broken leads on resistors 20*R* or 19*R*, or in line 29, as well as a short circuit between 33 and 7 would cause tube *C* to draw too much current and would ultimately prevent motor field current from flowing.

No Control of Field Voltage

Let us look now at the faults that would result in full-field voltage with no control. Since direct current flowing through the saturable reactor winding results in rectifier output voltage, anything that could cause direct current to flow in this winding should be suspected. A short circuit at the socket of tube *D*, between points 14 and 6, or 14 and 15, would give trouble. Also an open circuit in the circuit of resistor 25*R*, or a short circuit between points 15 or 17, and 16 or 5, would apply full field.

Tube *C*, which controls tube *D*, could have an open circuit in its plate or cathode circuit (lines 16 and 33, respectively). Also, tube *C* would not control if both contacts of *DB* were open (a dirty contact surface might prevent current from flowing); or if the upper contact were closed; or if any other part of the circuit between points 33*A* and 7 were open. An open circuit between points 33*A* and 7 might actually be traced down to a broken connection in the leads on the field section of the speed control—or to the speed-control potentiometer itself. This can be determined by resistance measurement of the potentiometer circuit.

Any failure such as a short between points 29 or 31 (tube *C* grid circuit), and any higher voltage point such as 6 or 27; or an open circuit in 5*VR* or 20*R* below point 29, which would allow the grid of tube *C* to become more positive than it should be, would also prevent control of the field voltage.

In order to simplify the field-control circuit of Fig. 6-23, tubes *E* and *F* were omitted. Let us look now at Fig. 6-15 which shows the circuits of these tubes. Insofar as control of the field is concerned, a fault in the circuits of tube *E* might result in full field with no control, while a fault in the circuits of tube *F* might result in no-field, or weak-field, conditions. Tubes *E* and *F* are in the current- and voltage-limit circuits and will be covered more completely later.

Armature Regulating Circuit

The method of breaking a circuit into its various subcircuits has been illustrated in previous examples. This method is actually automatically followed in one's mind as he traces possible troubles from one circuit to another. Let us continue through the remainder of the circuit with reference only to the entire diagram of Fig. 6-15 and see how the simple functional circuit elements can be automatically isolated from remainder of the diagram.

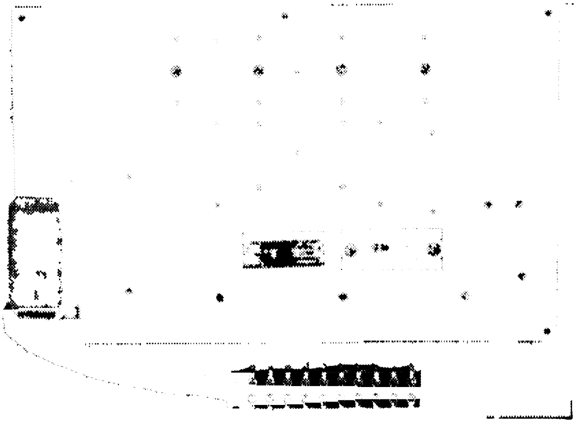


FIG. 6-24. Tube control panel for individual mounting in main unit of electronic motor control.

As was mentioned previously, tubes *C* and *D* each actually consist of two separate tube functions in one glass envelope. In this particular equipment tubes *C* and *D*, shown on the left, perform functions identical with the field-control tubes *C* and *D* shown on the right.

Circuit Same as Field Regulating Circuit

A careful comparison between circuits supplying *ASX* on the left and *FSX* on the right will show them to be practically identical. (Let us assume now that we are talking only about the functions of tubes *C* and *D*, and that the associated tubes are omitted.) Resistors 2*R*, 3*R*, and 4*R*, for example, perform the same functions in the armature circuit as resistors 15*R*, 16*R*, and 25*R* in the field circuit.

The cathode (point 20) of the left-hand tube *C* is connected to the speed-control potentiometer 7*VR* and minimum-speed potentiometer 6*VR* circuit in a little different manner than the other cathode (point 33 of tube *C* on right), which is connected to the circuit incorporating the dynamic braking contacts *DB*, speed-control potentiometer 8*VR*, resistor 27*R*, and maximum-speed potentiometer 3*VR*, because the field is controlled in the reverse sense of the armature. These differences, however, do not affect the basic circuit operation and should make no difference in the manner in which the two circuits are analyzed for possible troubles.

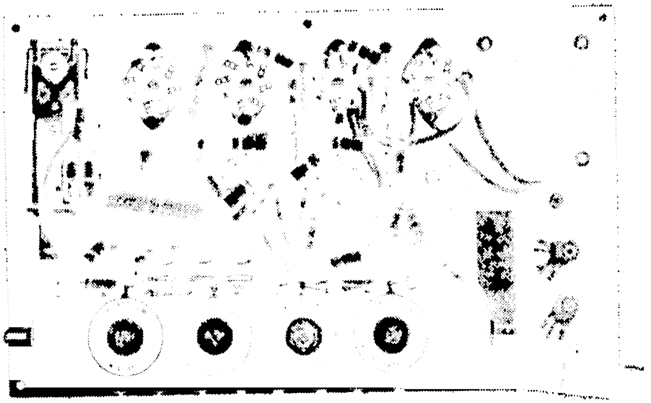


FIG. 6-25 Rear view of tube control panel showing chassis construction and relay for quick slowdown

Current Limit and *IR* Compensation Circuit

Current transformer 4*T* has two primary windings, one in each of the two armature rectifier-tube anode circuits. The current through these windings is transformed to a higher voltage and applied to the rectifier section of tube *F*, where it is rectified. An output voltage proportional to load is then applied to the two grids of tube *E* to control both the armature and field circuits.

Current Limit Too High

The failure of one thyratron armature tube or a short-circuited primary will cause the current transformer to saturate, and its output voltage to drop. A short circuit between any of the secondary leads will also mean lower output voltage. This means lower voltage applied to the grids of tube *E*, and a higher value of current limit.

A short circuit at the output of the rectifier; or between grid and cathode of tube *E;* or an open circuit in line 38, 12, 11, or 51; or resistor 23*R*, 22*R*, 6*R*, or 30*R*, or potentiometer 2*VR* will all make the current-limit circuit inoperative by preventing tube *E* (the current-limit control tube) from functioning.

Current Limit Too Low

Resistors 50*R*, 51*R*, and 52*R* are used as calibrating resistors on the current transformer. An "open" in the circuit of these resistors will unload the transformer and for a given armature current will result in a higher voltage output with a lower current limit value. An open circuit below (in voltage) the slider or potentiometer 1*VR* will reduce the current flowing in the potentiometer circuit and give a low current limit.

Other possible troubles could be shorted capacitors 11*C* or 9*C*, or other short or open circuits which would cause either section of tube *E* to conduct too much current.

IR Drop Compensation

The current-limit rectifier circuit, just discussed, supplies current through potentiometer 2*VR*. A voltage proportional to the slider position is fed into the armature regulating circuit to increase the armature voltage as load is applied to the motor. Because both the current limit and *IR* drop compensation circuits are supplied by the same rectifier, a fault in the current transformer or rectifier circuit will likely affect both functions in the same manner.

Improper current limit accompanied by proper *IR* drop compensation indicates that the current-limit rectifier is working properly, but that there is a fault somewhere in the circuits supplying the grids of tube *E*. If, on the other hand, there is proper current limit, yet no *IR* compensation, the rectifier circuit must still be OK. The trouble in this case is likely to be a shorted capacitor 4*C* or a short circuit between line 7 and lines 41 or 26.

Voltage Limit and "Preconditioning" Circuits

The triode section of tube *F* prevents too rapid application of field if the speed-control potentiometer is rapidly turned down from a high-speed position. Faulty operation of this circuit will be noticed either by flashing over of the motor commutator or by weakening of the motor field at low armature voltages.

If the field weakens at low armature voltage, tube *F* should be removed from its socket. If the field voltage then returns to normal the fault may be an open circuit in resistor 12*R*; or a short circuit between points 48 or 13 and a higher potential point; or a shorted grid capacitor 6*C*.

Flashing of the commutator might be caused by a short between points 48 or 13 and some more negative point; or by an open circuit in resistor 11*R* or 40*R*; or the associated wiring.

Tube *H* along with resistors 29*R*, 41*R*, 36*R*, 37*R*, and contact *M*, forms the preconditioning circuit for starting and for sudden speed changes. If either contact *M* or resistor 29*R* is open, the starting current at the first instant will be high and the motor will start with a bump. If resistor 36*R* or any of the circuits of tube *H* is open, a bump will result when the speed-control potentiometer is turned up rapidly.

Antihunting Circuits

Almost all regulating-type circuits require some "antihunting" components to provide stable motor operation. Although the operating circuits can be studied and understood without thinking about these circuits, the equipment will actually not work well without them. Wide speed fluctuations, pulsing of torque, and flashing of the thyratron tubes can usually be traced to defective antihunting components.

A resistor-capacitor combination often constitutes the antihunt circuit. Resistor 7*R* and capacitors 2*C* and 3*C* antihunt the armature circuit. The field antihunt circuit is a duplicate with resistor 17*R* and capacitors 7*C* and 8*C*. The current limit antihunt components are 5*R* and 11*C*, 28*R* and 10*C*, and 21*R* and 9*C*. In general, open circuits in any of these components will cause hunting under some operating conditions.

TABLE V.—TROUBLE-SHOOTING CHART

ELECTRONIC MOTOR CONTROL

Trouble	Cause	Remedy
Motor will not run.	A-c line fuses or panel fuses may be blown.	Replace with new fuses of same rating. If these blow in a short time, check wiring for short circuits. Do not replace fuses again until trouble is located.
	Cathode timer has not completed its cycle, or it may be defective.	Wait for timer to cycle. Repair or replace timer.
	Electronic tube may be defective or worn out.	Replace all tubes, one at a time, with tubes known to be good.
	Broken connection in power or control circuit.	Measure anode and control voltage at terminal board. Measure anode voltage at tubes. Measure control voltage at contactor coil or transformer primary. Look for broken lead in motor or control circuit or on panel.
	Tubes will not light because of open filament transformer.	Measure d-c resistance of filament transformer primary. This should be lower than 200 ohms. If primary is OK, check filament voltage at tube socket. If primary is open or if there is no voltage at tube socket, replace filament transformer.
	Open grid or control transformer or saturable reactor.	Measure d-c resistance of all windings. In general, none should be over 10,000 ohms. Replace if open.
	Open-circuited contactor or relay coil. Contactor will not pick up.	Measure voltage across coil. If voltage is present replace coil.
	Field failure relay drops out.	Check field circuit for continuity. Replace defective units.
	Overload relay has tripped out. Frozen machine bearings.	Reset relay and determine cause of overload. With the power off, turn motor by hand to be sure it is free.

TABLE V.—TROUBLE-SHOOTING CHART

ELECTRONIC MOTOR CONTROL (*Continued*)

Trouble	Cause	Remedy
	Temperature too low for tubes to ionize.	Install heaters or some other device for increasing panel temperature.
No control over motor speed.	Electronic tube may be defective or worn out.	Replace all tubes, one at a time, with tubes known to be good.
	Open grid transformer or saturable reactor.	Measure d-c resistance of all windings. In general, none should be over 10,000 ohms. Replace if open.
	Defective speed-adjusting potentiometer.	Examine potentiometer carefully to see if the internal connections are OK or, in case of defect, replace with a new unit.
	Broken connection in control circuit.	Look for broken lead on panel and in external potentiometer connections.
	Shorted grid-to-cathode capacitor on thyratron tubes.	Measure d-c resistance of capacitor. Replace if under 2 megohms.
	Temperature too high for power tubes.	Install sufficient ventilation to cool power tubes.
Speed erratic.	Dirty relay contact tips.	Clean all contact tips in all except power circuits.
	Defective electronic tube.	Replace all tubes, one at a time, with tubes known to be good.
	Loose connections in control circuit.	Tighten all control terminals and check connections for bad solder joints.
	Temperature too high for power tubes.	Install ventilation for power tubes.
Motor will not run above base speed.	Defective electronic tube.	Replace all tubes, one at a time, with tubes known to be good.
	Open grid transformer or saturable reactor.	Measure d-c resistance of all windings. Replace if open.

TABLE V.—TROUBLE-SHOOTING CHART
ELECTRONIC MOTOR CONTROL (*Continued*)

Trouble	Cause	Remedy
	Broken connection in control circuit or potentiometer.	Look for broken lead on panel and in external potentiometer connections.
	Shorted grid-to-cathode capacitor on thyratron tube.	Replace if d-c resistance is below 2 megohms.
Loss of current or voltage limit or speed regulation.	Defective electronic tube. Broken connections in control circuit or potentiometer.	Same remedies as listed above.
Control panel or anode transformer smokes.	Excessive load or short circuit on transformer.	Check external transformer leads for heating and short circuits. Replace transformer as it has been badly overheated.
	Internal fault in transformer.	Replace transformer.
	Shorted contactor coil or sticky magnet.	Be sure contactor closes firmly. Replace coil.
	Line voltage too high.	Measure line voltage to be sure it agrees with transformer rating. If too high, install voltage regulator or obtain special transformer.
Short tube life.	Excessive load.	Measure load with d-c ammeter to be sure it is not greater than panel name plate.
	Line voltage too high or too low.	Measure voltage to be sure taps on filament transformer agree.

CHAPTER 7

INSTALLING, MAINTAINING, AND SERVICING ELECTRONIC RESISTANCE-WELDING CONTROL

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Careful planning should always precede the actual installation of any type of electrical equipment. This is especially true in the case of the electronic controls of the resistance welder. Extraordinary consideration should be given the power supply, and the wiring to the control. Prolonged shutdowns can be eliminated largely with adequate protection for the power system, proper cooling water for the ignitron power tubes, and accurate checking and recording of the operation of the electronic tubes. If, in addition, the proper auxiliaries, spare parts, tubes, and adequate instruments are readily available, repairs can be made promptly and even brief shutdowns materially reduced.

General Installation Considerations

Location. The physical size of the control is usually determined by the size of the welding machine that it operates. Most small welding machines up to 3 kva are bench-mounted, and in most cases the controls are small enough to mount on the bench alongside them as in Fig. 7-1.

If necessary, the control can be mounted under the bench, but this is not recommended and should be done only as a last resort. For one thing, such a location is generally subject to greater dust accumulation. For another, the control is exposed to a number of dangers from mechanical abuse to the possibility of metallic objects falling into the ventilating louvers and causing shorts. Servicing of the control is invariably complicated by the presence of material trays and tote boxes, which in addition, tend to reduce the ventilation required by the controls, thus shortening the life of the tubes and parts. Furthermore, it is difficult for servicemen to work efficiently in a cramped position beneath the bench with the generally inadequate light.

In applications where several welding machines operate from a single control, the panel should be situated at one end of the bench supporting the welders. However, the practice of operating more than one welder from a single control is not recommended since it is generally uneconomical. In the first place, a complicated interlocking system is required; and second, production speed is materially reduced, resulting in a lower over-all production efficiency.

FIG. 7-1. Control panels of small bench units should always be mounted atop the bench, never beneath.

Controls designed for welding machines larger than 3 kva are floor-mounted and can be located remotely or close at hand, depending on the space allowed for the welding setup. A larger welding machine will sometimes have the control panel mounted within the machine frame, as shown in Fig. 7-2. This eliminates the problem of locating and installing the control. In such cases, it is highly desirable to mount the welding machine so that the portholes and doors of the machine frame are accessible.

In the majority of installations, control panels are located adjacent to the welding machines, as shown in Fig. 7-3. This is particularly desirable where a variety of work is to be done on a single machine. Placing the control within convenient reach of the operator enables him quickly to change the time and heat settings, as necessary. Again, provision should be made to permit servicemen ample room completely to open control-panel doors. The practice of piling stock close to the control should be avoided, and operators given instructions to that effect.

Circuit breakers, fuse boxes, meters, and other controls associated with the welding machine should be mounted near the main control panel. A neat appearance is accomplished by mounting these parts on angle-iron frames set on the floor, or running from floor to ceiling.

To facilitate the keeping of records, each of the welding machines should be given a number and each electrical device associated with it, the same number followed by an alphabetical letter. Identifying numbers and letters should be plainly printed or painted on each piece of equipment.

For large production installations where a number of welding machines are in the same area, and where control settings are seldom changed, it is often advantageous to mount all the controls on a balcony above or near by the welding area (Fig. 7-4.) The centralization of all welding controls assures accessibility at all times and results in efficient servicing. Also, mounting the controls above the floor makes it possible to place the welding machines closer together, thus conserving valuable floor space and eliminating the possibility of damage to the controls by floor trucks and careless personnel. In addition, floor installations require each individual panel to be locked to prevent unauthorized persons from tampering with the control; with balcony installations, only the door of the stairway leading to the balcony needs to be locked.

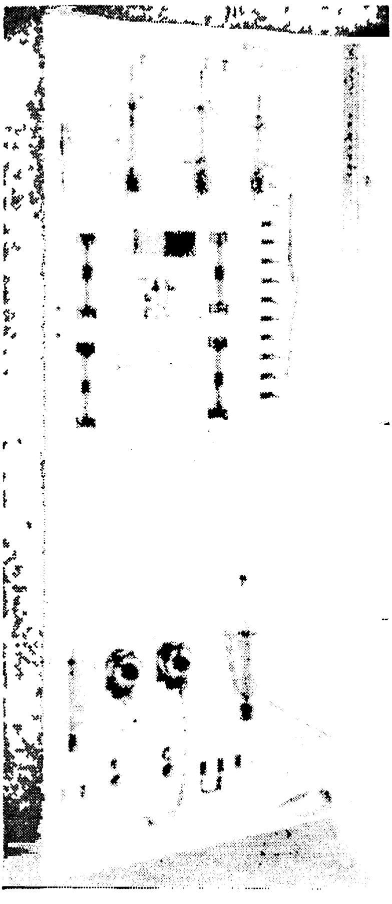


FIG 7-2 The control panel for a large resistance welder is sometimes mounted within the machine frame.

The above recommendations also apply to gun welders and other forms of portable welding equipment. Where space is limited or when the control panel might be subjected to mechanical shocks, it is generally advisable to mount the control at some distance from the welding machine and to install the control dial plate on (or in) the welding machine frame, as shown in Fig. 7-5.

Power Supply. Resistance-welding machines generally impose a large intermittent single-phase load at low power factor on the distribution system. The power factor is usually between 25 and 50 per cent, which is low compared with that of other electrical apparatus. The reason for this unusually low power factor lies primarily in the physical configuration necessary in the machine parts carrying the welding current from the welding transformer to the electrodes. That is, it is necessary to separate the two arms in order to insert work between the electrodes. The greater the separation and the longer the arms, the lower will be the power factor.

FIG. 7-3. Electronic controls in the majority of installations are located adjacent to the welding machines.

Because of the nature of resistance-welder loads, it is advisable to have a separate low-voltage feeder throughout the welding area. The step-down power transformer supplying this feeder should be located as near as possible to the welding controls. Long feeder lines should be avoided since, the longer the line, the greater the voltage regulation at the welding machine. Most electronic welding controls will tolerate up to 10 per cent voltage variation without changing timing.

A better welding installation may be obtained by using a separate power transformer for each welding machine, located as near as possible to the control and the machine (Fig. 7-6). With such installations, it is not necessary to consider possible electrical interference to other welding machines since very little will be transformed back to the high-voltage feeder. Separate transformers for each welder may not be economical in large production factories, but a compromise should be arrived at whereby not more than two or three machines operate from a single power transformer. Interference or regulation problems are almost always the result of attempting to operate a large number of welders from a low-voltage feeder of insufficient capacity.

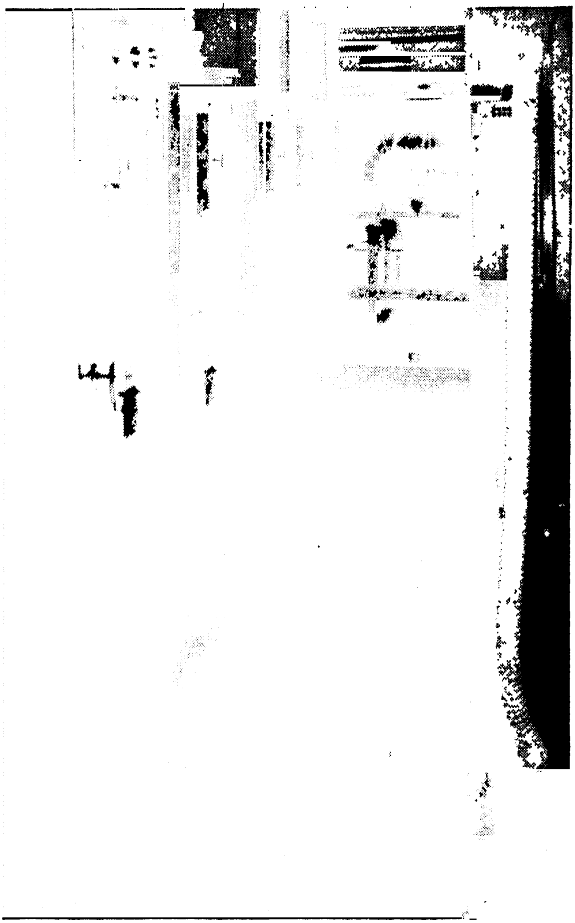


FIG. 7–4. Balcony-mounted control saves floor space in addition to other advantages when settings remain unchanged.

In factories where voltage variation and regulation exceeds 10 per cent, accurate timing and control may be assured if a separate source of power is used for the control panel. *However, the same electrical phase relation should exist between main welder power and control power.* Most welding control panels have provisions in the wiring for easily isolating the control circuit. The wiring diagram of the welding control panel will describe the wiring changes necessary to isolate this circuit.

Regardless of whether the same or a separate supply is used for the control and the welder, it is advisable to install a control power switch which will enable the control circuit to be energized when the main power switch or circuit breaker is open. Thus, in case of trouble, measurements may be made in the control circuit without applying power to the welding machine.

FIG. 7–5. Remote heat and timing dials are shown mounted within the machine frame of this seam welder.

Lack of Service Capacity. In some cases, a large resistance-welding load presents such difficulties to the utility supplying the power that it is found necessary to apply restrictions to the use of such equipment. Some of the reasons for these restrictions follow:

1. Flickering of lights each time a weld is made.

2. Interference with other electrical apparatus on the same line.

3. Tripping of circuit breakers as caused by the high current surges.

In such instances, the supply problem may be simplified with the use of capacitors placed in series with the primary of the welding transformer to improve the power factor of the welder to unity. The consequent reduction in kva demand will bring about the following beneficial results:

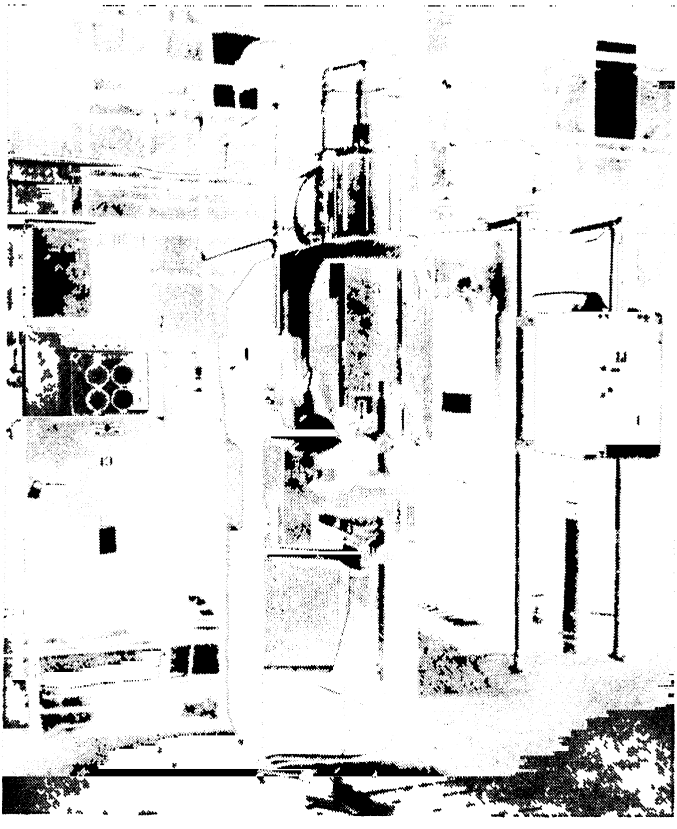


FIG 7-6 Individual power transformer (2 300 to 460 volts) supplies welder Note high-voltage cutouts, low-voltage air circuit breaker, and control panel

1. Welding machines may be installed on existing feeders too small to supply the usual low-power-factor machines.

2. Heavier welds are possible from a given feeder.

3. Inteference with other welders and apparatus on the same feeder is minimized.

4. Light flicker is reduced or completely eliminated.

5. Special low-impedance power-supply transformers are not needed.
6. Additional machines can be used on the same feeder, provided all are equipped with series capacitors.

Series capacitors can be applied to spot, projection, seam, and butt resistance-welding machines. They can also be applied to existing welding machine installations, but because of the nature of the electrical circuit, welder transformer and capacitor voltages are increased above the line voltage. For this reason, it is necessary to use control equipment and welding transformers suitable for these higher voltages.

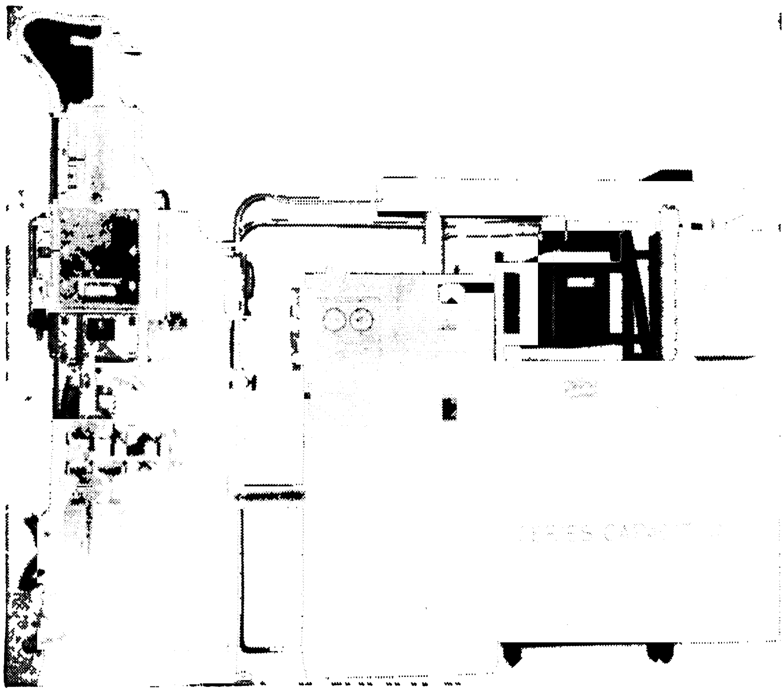


Fig. 7-7. Two floor-mounted cabinets on extreme right house series capacitors for this spot welder.

Because of this size, capacitor banks for large machines are usually mounted at some remote point, such as on a balcony. On smaller installations the capacitor racks are mounted near the welding control as shown in Fig. 7-7. Being static devices, capacitors present practically no maintenance problem. For this reason, they are often suspended from the ceiling or mounted at some remote point to conserve valuable floor space.

Wiring. Of the two classes of wiring, open and conduit, the latter is preferred for welding installations. Although open wiring is altogether cheaper and easier to install, the inherent advantages of conduit wiring will justify the additional time and expense involved.

As in the case of the electrode arms of the welding machine, the farther apart the feeders are placed the greater will be the reactance, and hence the greater will be the voltage drop in the feeder. If open wiring is used, the installation should be made with the feeders as short as possible and placed as near together as electrical codes will permit.

There have been a number of instances where the use of open wiring for welding machines resulted in noisy radio reception and faulty functioning of other electrical apparatus in the immediate vicinity. Because of the standing electric waves set up on the open feeders, conduit wiring will eliminate or greatly reduce this interference. Certainly open wiring should not be installed in a factory located in an urban residential center. Originally, open wiring was used exclusively in many of the hurriedly constructed war plants throughout the country. However, because of interference between the welding machines themselves it later became necessary to change over to conduit wiring, with a consequent loss of time and production.

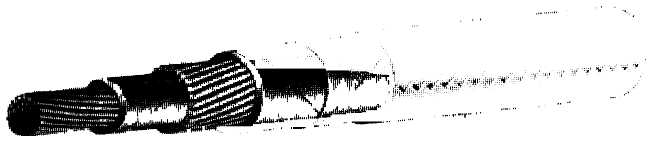


FIG. 7-8. Concentric cable of two conductors used for welder feeders because of low voltage drop and low initial cost

Because of its low voltage drop and low initial cost, a concentric cable (Fig. 7-8) has been designed for feeders to resistance-welding machines. The two-conductor, concentric construction was selected primarily to improve voltage drop.

The two factors that govern cable selection are heating and voltage drop. With such cable, it is possible to make longer runs with substantial savings in copper.

The customary step-by-step method of selecting conductor size is as follows:

1. Select the proper conductor size from Table VI for the known "during-weld" primary current and duty cycle. (The averaging time for determining the duty cycle should not exceed 1 min.)

2. Check in Table VII to determine whether the voltage drop at rated current will be satisfactory. Because a 5 per cent voltage drop has been found to be an economical figure, Table VII has been calculated on that basis. Hence, select the proper conductor size from this table for the known "during-weld" current and distance from load to source of supply.

TABLE VI.

FEEDER CABLE SIZES FOR RESISTANCE-WELDING MACHINES FOR 440-VOLT, 60-CYCLE, SINGLE-PHASE CIRCUITS. 85°C COPPER—40°C AMBIENT. CABLE IN CONDUIT.

During-weld current, amperes	Conductor size (AWG or MCM), based on heating			
	Duty cycle, per cent			
	5	10	30	70
100	8	8	6	2
250	6	4	0	0000
500	2	00	300	600
750	00	250	600	1250
1,000	0000	400	1000	2500
1,500	400	750	2500	
2,000	700	1250		
2,500	1000	2000		
3,000	1500			
3,500	2000			
4,000	2500			

Use the larger size of the two conductors as indicated by reference to Tables VI and VII.

If a 220-volt supply is used, Table VI will still apply for the selection of conductor size from the heating standpoint. However, in using Table VII, the actual distance from the supply transformer to the welder should be multiplied by 2 and the conductor size selected on that basis. For example, if the actual distance is 200 ft, the conductor should be determined by taking the size given under the 400-ft column in Table VII.

Circuit Protection. Welding machines demanding up to 100 amp line current are usually protected with a fused knife switch placed near the welding control. The larger machines, 100 amp and up, should employ circuit breakers equipped with instantaneous trips that will promptly and safely intercept overcurrents or short circuits (within the breaker rating), Fig. 7-9. The fused switch box, being a manually operated device, should be mounted within reach of the operator. Circuit breakers are available in manually or electrically operated types. The electrically operated breaker is preferred, since it can be operated from a push-button station mounted on the welding machine while the breaker itself is mounted at some remote location.

TABLE VII.

FEEDER CABLE SIZES FOR RESISTANCE-WELDING MACHINES FOR 440-VOLT, 60-CYCLE, SINGLE-PHASE CIRCUITS. CABLE IN CONDUIT.

During-weld current, amperes	Conductor size (AWG or MCM) based on 5 per cent voltage drop in cable when load is applied*					
	Distance, feet from supply transformer to welder					
	50	100	150	200	300	400
100	8	8	8	8	6	6
250	6	6	6	4	2	2
500	2	2	2	2	0	00
750	0	00	00	00	000	0000
1,000	0000	0000	0000	0000	0000	300
1,500	400	400	400	400	400	500
2,000	700	700	700	700	700	800
2,500	1000	1000	1000	1000	1000	1250
3,000	1500	1500	1500	1500	1500	2000
3,500	2000	2000	2000	2000	2000	3000

* This voltage-drop table was prepared on the basis of a 30 to 40 per cent power factor, which should cover nearly all cases except where power-factor-correction methods are used. For power factor outside this range, the voltage drop may exceed the 5 per cent allowable drop and require the use of a larger conductor size.

The air-type circuit breaker, with its instantaneous trip, will immediately interrupt the feed circuit upon failure of an ignitron power tube to function properly in a welding control. Incorrect operation of the control usually results in a d-c current component. This d-c current in turn saturates the iron core of the welding transformer, resulting in

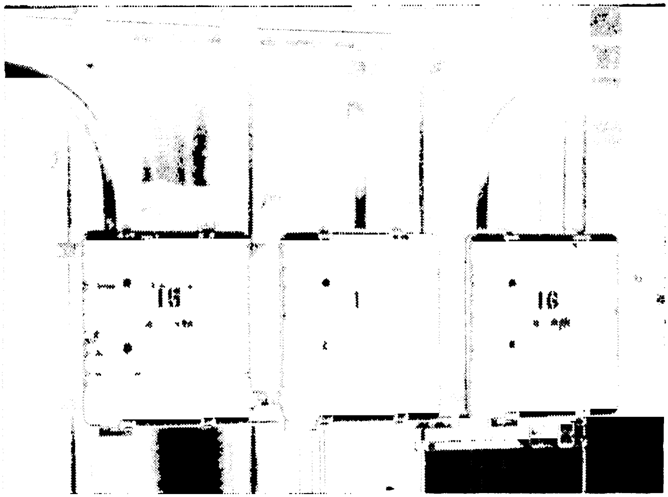


FIG. 7-9. Low-voltage air circuit breakers protect individual welders supplied by this 2,300- to 460-volt power transformer.

FIG. 7-10. Water-cooled welding transformer showing series water connections.

instantaneous high a-c current transients. Under such conditions a fuse or a thermal relay and contactor may not open the feed circuit, as thermally operated devices are too slow to operate on instantaneous values of current. However, the instantaneous trip, when adjusted within the current rating of the ignitron tube, will open the breaker to protect the tubes upon the occurrence of dangerous overcurrents occasioned by circumstances beyond the control of the welder operator. Manufacturers of circuit breakers can supply tables which will be helpful in selecting the proper size of breakers for any welding installation.

A form of overvoltage protection should be used on power-factor-corrected installations where the capacitor units have a maximum permissible voltage rating that would be exceeded under short-circuit conditions (with the welder electrodes directly shorted). This equipment should automatically by-pass the capacitors under short-circuited conditions. When series capacitors are used with resistance welders having synchronous electronic control, it is necessary that a charge be left on the capacitors between successive welds. For this reason, a discharge resistor and contactor should be installed to discharge the capacitors totally when the equipment is shut down. When either nonsynchronous electronic control or mechanical contactors are used, the discharge resistor is permanently connected across the capacitor bus.

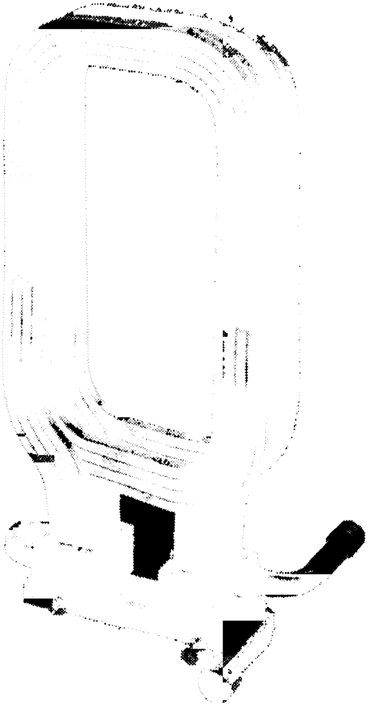


Fig 7-11 Secondary coil assembly of a water-cooled welding transformer

To avoid interference problems and also as a precautionary safety measure, all enclosures and frames should be grounded. The wiring diagrams for the control apparatus should be inspected to determine if any circuits are to be grounded. Long runs of conduit should be grounded at both ends. For small bench welders and machines up to 100 kva rating, a stranded No. 2 (AWG) wire may be used. On installations larger than 100 kva, 3/0 or 250 MCM wire should be used.

Cooling Water. The welding transformers on all resistance-welding equipment except the smallest bench welders, are cooled by circulating water through the welding transformer secondary windings (Figs. 7-10 and 7-11) and through the welding electrode. Because of the sharp bends and small orifice through which the water must pass, it is

imperative that clean, clear water is used. On certain types of work, better welds and increased electrode-tip life will result if a refrigerant, instead of water, is circulated through the electrodes alone. This usually involves setting up a separate refrigerating unit near the welding machine, although on some of the newer equipments this unit is built into the welder frame.

All electronic resistance-welding controls using ignitron power tubes also require cooling water to be circulated in the outer jacket of each tube. It is important to maintain the proper rate of flow as well as water temperature through these tubes. Table VIII lists the required flow as well as the maximum inlet and outlet temperatures for the most common classes of ignitron tubes. As in the case of the welding machine, clean clear water only should be used as a coolant. The process water of a factory is usually too warm during the summer for use in the ignitron tubes; its temperature should be checked with the figures shown in Table VIII. For this reason, city or plant drinking water is generally used for cooling.

TABLE VIII.

Tube size (2 tubes)	Minimum water required, gal per min	Maximum water temp., outlet	Approximate maximum inlet water temp.†
A	1	40°C/104°F	37°C/99°F
B	1	40°C/104°F	35°C/95°F
C	1½	40°C/104°F	32°C/90°F
D	3	30°C/ 86°F*	16°C/61°F

* This maximum outlet temperature may be increased to 40°C with a reduction of 30 per cent in the duty cycle for any specific current.

† The maximum allowable inlet temperature may be increased by increasing the water flow.

In plants using a large number of welding machines, it is sometimes economical to install a reservoir circulating system instead of exhausting the cooling water into the sewer. If process water is to be used, a strainer should be installed at a point just before the water enters the control panel. This strainer should be cleaned frequently to prevent clogging which might reduce the rate of water flow.

Most all electronic welding controls employing ignitron tubes contain some form of water interlock or flow switch to ensure the flow of water through the power tubes during welding. Two of the most common types are shown in Figs. 7-12 and 7-13. Both of these types are thermal and require approximately 1 min to operate after power is applied when water is not flowing. These thermal flow switches are constructed to ensure the proper water temperature and flow. The thermal switch acts to prevent operation of the control when the rate of flow decreases or if the water temperature exceeds 40°C.

There are several forms of pressure switches used to ensure water flow. However, these do not respond to clogged outlets since, even if the water does not flow. the pressure is maintained.

The length of water hose between the power tubes, or a tube and metal water pipe, should not be less than 24 in. in order to maintain the proper electrical clearances. To prevent air pockets, the cooling water should always enter the bottom of an ignitron tube and exhaust at the top.

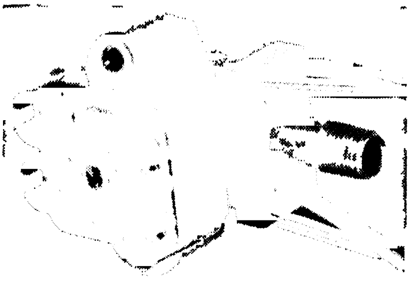


Fig. 7-12 Heater-type flow switch.

Tubes. Electronic resistance-welding control panels employ almost all classes of electronic tubes: phanotrons, thyratrons, ignitrons, glow tubes, and radio receiver-type tubes. The smaller size tubes, such as the glow, receiver type, and some small thyratron tubes, require only the care given ordinary radio tubes. Certain equipments are shipped with these tubes mounted in their respective sockets and hence require no special treatment before they are placed in operation. The large thyratrons, which are wrapped and shipped in separate cartons, should be placed in their respective sockets in accordance with the panel wiring diagram or marking on the panel.

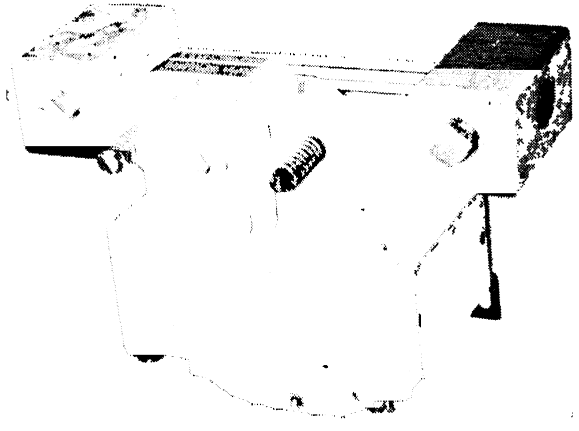
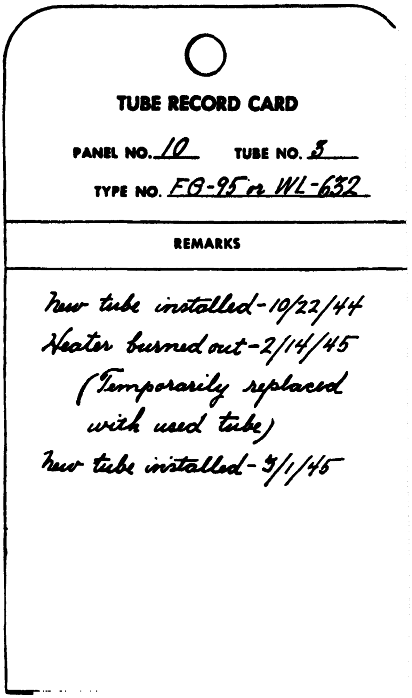


Fig. 7-13 Transformer-type flow switch

When these tubes are first installed, they must be heated for at least 15 min, *with the anode and grid caps removed,* in order to permit the mercury to be evaporated from the tube elements. After this preliminary heating period, *remove power* and replace the caps. The control time-delay relay will give sufficient time for cathode heating for all subsequent operations of the control. If a new tube is inserted at any time, this 15-min period of preliminary heating should be repeated.

Ignitron power tubes should be carefully removed from the crates or boxes in which they are shipped and bolted to the bus supports in an upright position. Connect the anode lead to the proper stud or bus. If, when installing, it is necessary to twist this braided lead, turn the lead in the direction required to unwind the braid since tightening may set up unnecessary stress in the glass anode seal. Be sure to connect the ignitor, which extends from the bottom of the tube, to the proper terminal as shown on the panel wiring diagram. Operators not familiar with metal ignitron tubes should be cautioned that the *outside jacket is at line potential* when the main power switch is closed. Ignitron tubes do not require any conditioning before being used for welding operation.



TUBE RECORD CARD

PANEL NO. 10 TUBE NO. 3

TYPE NO. FG-95 or WL-632

REMARKS

New tube installed-10/22/44

Heater burned out-2/14/45

(Temporarily replaced with used tube)

New tube installed-3/1/45

FIG. 7-14. A tube record card such as this should be maintained for each tube socket.

Accurate records should be kept of all tubes in each control. This record will be a means of determining if the tube has met the warranty issued by the supplier. An example of a record card is shown in Fig. 7-14. A separate card should be kept for each tube socket in the panel and may be placed on a hook or in a rack in the control panel, or in a central file in the maintenance office for ready reference.

It is most advisable to have a convenient 115-volt, 60-cycle outlet near each welding machine or control. The purpose of the outlet may be threefold. In case of trouble, it can be used as a source of power for a droplight or soldering tool. During welding it may be used for a spot or work light. And last, but most important, the cathode-ray oscilloscope requires a 115-volt, 60-cycle source of power for operation. In order to avoid problems of synchronization, *it is important that the 115-volt power be obtained from the same power circuit as that used for the welder.*

When cadmium or zinc-plated parts, as well as leaded steels, are to be welded, modern safety codes require that some form of fume collector be mounted near the welding electrodes. The possible poisonous gases emitted during the welding of these materials should be exhausted to the open air.

In welding installations where a variety of work is to be done, a good practice is to build a cabinet or rack to hold the various electrode tips. This should be mounted near the welder and locked when not in use, to prevent other operators from using the tips improperly.

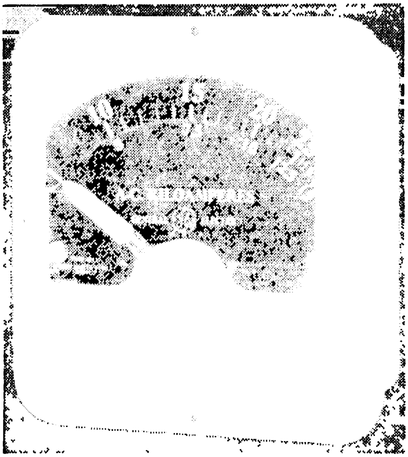


FIG. 7-15. Adjustable pointer-stop a-c ammeter.

Instruments. When using resistance welding machines, such as spot, projection, and seam welders, it is desirable to know the actual welding current, so that the data accumulated on one machine can be used in connection with other machines and other materials. Also, knowing actual current values is often helpful in trouble shooting, thus facilitating proper maintenance. A pointer-stop ammeter is used for measuring welding currents of short duration (Fig. 7-15).

The term "pointer-stop" has been applied to indicating instruments equipped with an adjustable pointer-stop (in addition to the stop, or stops at the scale end normally provided to prevent overtravel of the pointer). This pointer-stop may be adjusted by an external knob. In ammeters, this stop is arranged so as to push the pointer up scale; in the case of voltmeters, the setting is reversed.

The welding current can be determined, either by means of a pointer-stop ammeter connected to a suitably rated current transformer directly connected in the welding-transformer secondary circuit; or by measuring the primary current, and multiplying this by the ratio of transformation. The latter method is usually preferred, since often it is inconvenient to install permanently a current transformer of adequate capacity in the secondary circuit. Figures 7-3, 7-5, and 7-7 show panel-type pointer-stop ammeters permanently mounted at the welding control or machine.

The maintenance department should add the following instruments

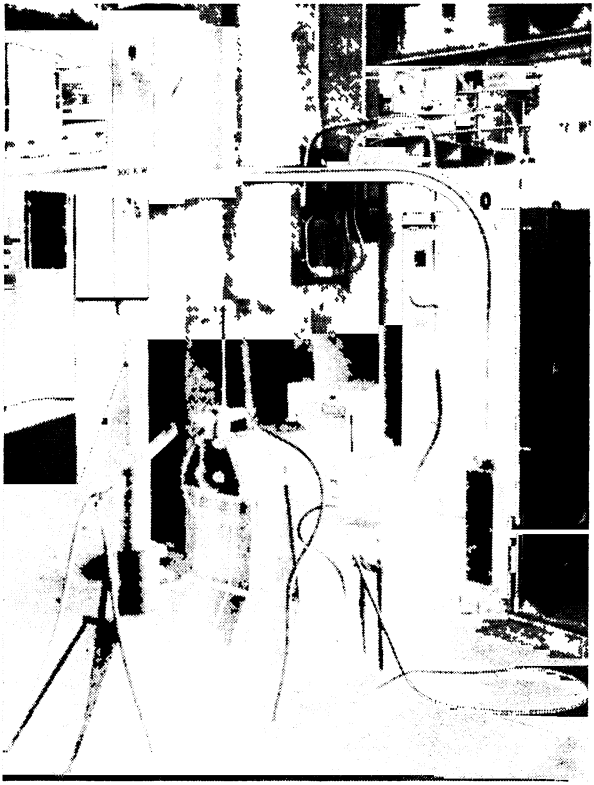


FIG. 7-16 Special spot welder with thyratron control to meet miscellaneous unusual requirements

to its service equipment if quick and successful trouble shooting is to be done on electronic resistance-welding controls:

1. A reliable volt-ohmmeter.
2. A 3-in. cathode-ray oscilloscope (modified to read direct current).
3. A split-core current transformer and portable pointer-stop ammeter, or a clamp-on pointer-stop ammeter.
4. Receiver-type tube tester (optional).
5. Cycle recorder or counter (optional).

The use of these instruments in servicing welder controls will be described in detail later on.

Spare Parts. Spare tubes, transformers, dry-type rectifiers, fuses, and indicating lamps are the most important items to keep in the spare-parts cabinet of the maintenance stock room. The small resistors and capacitors used on most controls should also be kept in stock but can be temporarily replaced with parts obtainable in local radio-supply stores. Most welding-control manufacturers have spare-parts lists already prepared which will give the necessary catalogue numbers required for ordering.

FIG. 7-17. Thyratron half-cycle welding control panel used with bench welder for spot-welding vacuum-tube assemblies.

Upon receiving the wiring diagram for a welding control, it is important to examine the material list and make sure that your stock room has at least one spare of each of the various tubes used in the control. The quantity stocked should be governed by the number of welding controls located in the plant. Determine from this material list the catalogue numbers of transformers and dry-type rectifiers. These parts should also be stocked according to the number of controls employed and the degree of regularity with which they are used.

The conventional voltage transformers can be temporarily repaired or rebuilt in the average maintenance shop. However, there should be spare transformers on hand. The most popular controls generally employ the type of relays used on other forms of electrical apparatus and so in all probability are already carried in the stock room. Special forms, such as telephone and time-delay relays, should be added to the spare-parts stock.

A record of all replacements, as well as other service information, should be filed in the maintenance office. If an individual record is kept of each welding control, it is convenient to file the previously mentioned tube-record cards along with this information. In case of trouble, reference to these records will facilitate prompt repair.

FIG. 7–18. Alternating-current resistance-welding equipment (control on balcony) in a large aircraft plant.

Major Components

The ignitron contactor is one of the simpler forms of electronic controls used with resistance-welding machines. Acting only as an electronic contactor, it affords no phase or heat control in itself. Therefore, the timing of the weld is controlled by the length of time the starting or initiating switch is closed. The welding current then starts immediately, and for this reason transient current may flow for the first few cycles, depending upon the point in the cycle when the switch is closed. The weld then continues as long as the operator holds the switch closed. If reasonably accurate timing is desired, a weld timer may be employed which has an adjustable time setting to initiate the ignitron contactor for a time interval of several cycles, usually 3 to 60 cycles.

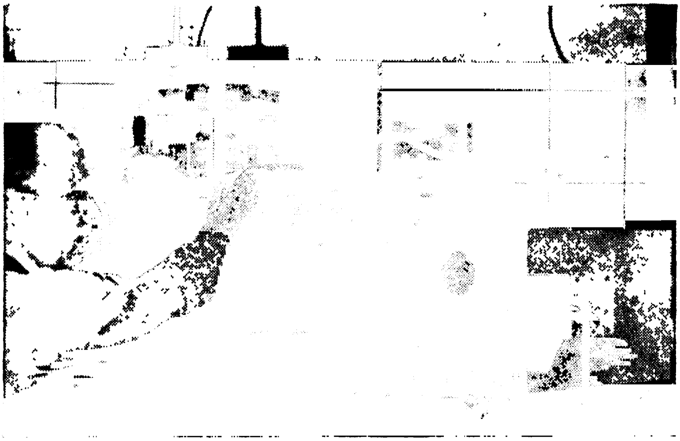


FIG. 7-19. Flash-welding machine being checked with oscilloscope and voltmeter.

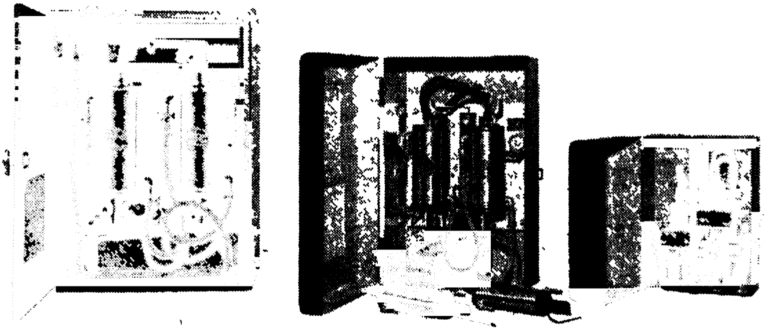


FIG. 7-20. Typical ignitron contactors for resistance welders (left to right and mounted in cabinets): Size *D* tubes, size *C* tubes, size *A* tubes, and two size *B* tubes are shown in front lying on table.

Ignitron Contactor

Although there are several forms of ignitron contactors, they usually differ only in size and type of ignitron tubes that can be accommodated

(Fig. 7-20). The electrical operation is practically the same for all sizes. For this reason, the tests that are explained will be the same for all forms. In the elementary diagram of Fig. 7-21, it will be noted that the most complex items to test are the copper oxide rectifiers and the ignitron tubes.

If faulty operation is experienced when the ignitron contactor is first installed, do not hastily blame the control, since in many instances the trouble is faulty external wiring. In the case of trouble occurring some time after the control has been operating, Table IX will be helpful in locating the source of trouble.

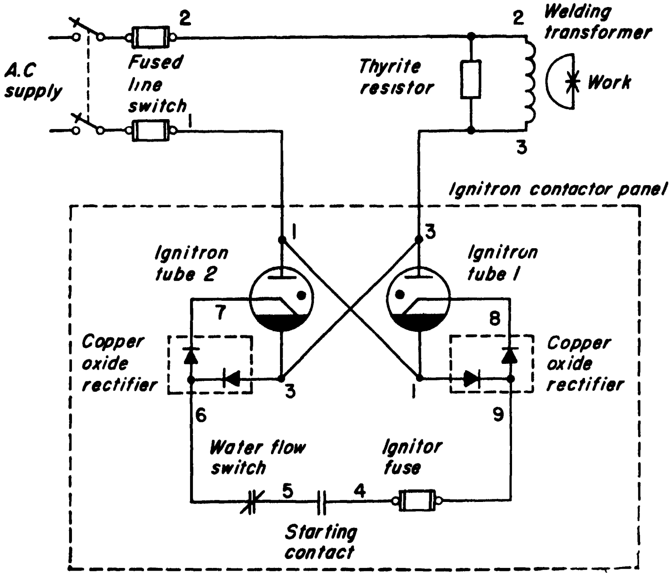


FIG. 7-21. Elementary circuit diagram of an ignitron contactor.

Copper Oxide Rectifiers

There are usually two copper oxide rectifiers in each ignitron contactor, one operating in each ignitor circuit. The purpose of the rectifier is to allow the a-c line voltage to pass through the ignitor the instant the anode of the particular tube is at positive potential. This strikes the arc (closes the circuit) and current flows for the half-cycles during which the anode is positive.

The copper oxide rectifier consists of a series of copper disks stacked together on a common stud. Each disk is clean on one side and oxidized on the other. Electric current can easily flow from the oxide surface into the copper while a high resistance is offered to current flow in the opposite direction. Shown in Fig. 7-22 is a typical rectifier of the copper oxide type. It is important that the terminals be properly connected into the ignitor circuit. Terminal markings should be checked with the wiring diagrams.

A defective rectifier may sometimes be located by inspection. If the insulation has failed or for some reason there has been an arc-over, the defective rectifier will have a burned or blackened appearance. In some instances of severe failures, molten metal may be expelled from the rectifier. No attempt should be made to repair a defective rectifier since special methods are used in its manufacture which cannot be duplicated by the average maintenance department.

FIG 7-22 Typical copper oxide rectifier

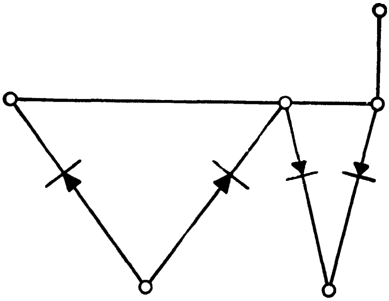


FIG. 7-22A. Elementary diagram of typical copper oxide rectifier.

If visual inspection fails to reveal a defective rectifier, an electrical test must be performed. The rectifier should be disconnected from the circuit and the electrical resistance of each unit measured in the forward and reverse direction (Figs. 7-23 and 7-24). If a battery-type ohmmeter is used in making these measurements, the resistance in the forward direction will be approximately one-quarter of that in the reverse direction, provided that the rectifier is in good condition. A defective rectifier will usually have the same resistance regardless of the direction of measurement. A battery-type ohmmeter operates on 1½ to 7 volts. Because of this low voltage, the difference between the forward and the reverse resistance is rather low. Actually, when the rectifier is operated at rated voltage, the resistance in the reverse direction is several hundred times that of the forward direction.

Ignitron Tube

The top of anode connection of an ignitron tube consists of a braided copper lead and terminal. The larger rigid connection at the bottom of the tube which acts as a support is the cathode terminal. It is between these two connections that the primary welder current flows. For this reason, they should be tightly connected to clean surfaces to prevent any electrical heat losses.

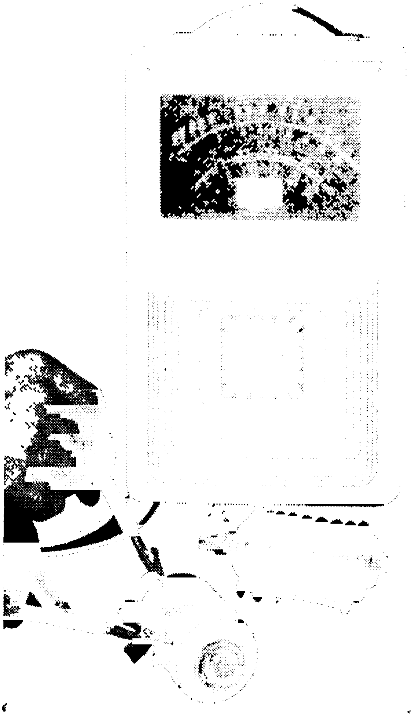


FIG. 7-23. Ohmmeter being used to test copper oxide rectifiers. Resistance is being measured in forward direction.

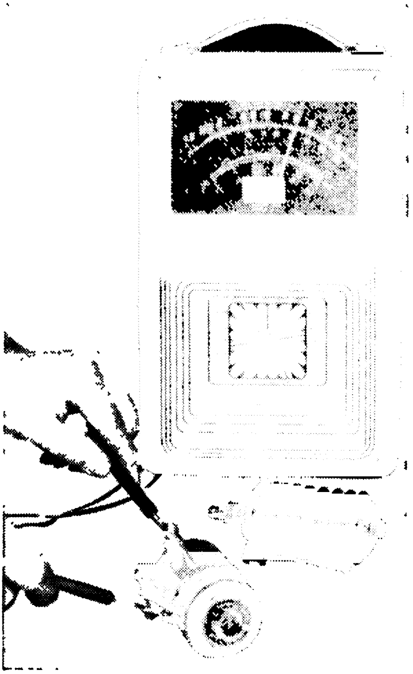


FIG. 7-24. Test clips are reversed on the terminals of the copper oxide rectifier to measure "reverse" resistance.

The small flexible lead, extending from the bottom of the tube, is the ignitor connection. The purpose of the ignitor is to start or "trigger" the tube and cause conduction of current from the anode to the cathode. Inside each tube there is a pool of mercury which, when the tube is properly mounted, just touches the tip of the ignitor. For this reason, when testing a tube it should be held or mounted in its normal operating position.

Visual inspection very seldom reveals a defective ignitron tube.

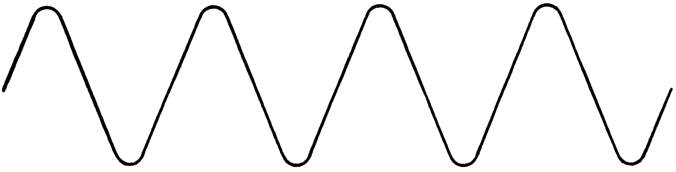
Usually it is necessary to perform an ignitor resistance test and a gas test to determine the condition of the tube. With a battery-type ohmmeter, the ignitor resistance is measured between the ignitor and cathode connections. The resistance should be measured in both directions and the average value used. A good tube may show resistance values of from 5 to 500 ohms. However, more often the value will fall between 10 and 150 ohms. When measuring ignitor resistance, always disconnect the ignitor lead to avoid measuring the resistance of a parallel circuit.

Gassy Tube Tests. When air leaks into an ignitron tube, it is said to become "gassy." This condition is usually identified by the tube continuously passing current even when the control is not initiated. The current flow can be detected by the appearance of a light bluish glow seen in the tube through the glass anode seal at the top. If a tube is thought to be gassy, remove power from the panel and disconnect the ignitor. Reclose the line switch, and if the tube gives evidence of passing current replace it with a new one.

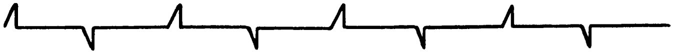
A further gas test may be made on an ignitron tube with the use of a high-voltage spark coil (induction type). To test the tube, remove power and disconnect the anode terminal from the bus or stud connection. Bend the braid so that the terminal almost touches the outside cylinder of the tube. If the test spark coil will draw a ½- to ¾-in. spark, place the terminal approximately 1 in. from the cylinder. When the spark coil tip is touched to the anode cable, there should be no sparking, or pink or orange glow inside the tube for more than a few seconds. Next, press the spark coil tip against the anode lead so as to decrease the gap between the terminal and the cylinder. Before this gap decreases to ³⁄₁₆ in., a spark should occur across the gap. If there is sparking or glowing inside the tube when the gap is approximately ½ in., the tube is gassy and should be replaced.

When an ignitron tube is nearing the end of its useful life, it becomes "hard starting" and occasionally causes the ignitor fuse to blow. Replacing the fuse sometimes allows the tube to operate for some time before the fuse is blown again. In order to check properly a hard-starting tube, it is necessary to use a cathode-ray oscilloscope, commonly referred to as a "scope." With a reference voltage of the supply frequency, the scope should be synchronized to show a four-cycle sweep (Fig. 7-25). Place the negative lead of the scope on the cathode connection and the positive lead on the ignitor connection. The ignitor voltage, in which we are interested for this tube, will appear above the zero axis. When the contactor is operated, the ignitor voltage will appear as shown in Fig. 7-25. Note the similarity of the peaks of voltage. The ignitor voltage of a hard-starting tube will appear unstable, and the magnitude (height) of the peaks will vary from cycle to cycle (Fig. 7-25).

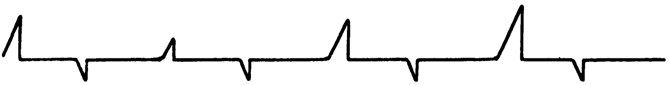
Auxiliary Loading. The minimum current that can be controlled in a satisfactory manner by ignitron tubes is 40 amp inductive welding load. Where the primary welding current is less than 40 amp, a suitable shunt resistor or reactor must be connected across the terminals of the welding transformer. Some ignitron tubes will not conduct while others will intermittently pass current when the load current is less than 40 amp.



(A) A C. supply (with four cycle sweep)



(B) Ignitor voltage (good tubes)



(C) Ignitor voltage (one tube hard starting)

FIG. 7-25. Screen views of cathode-ray oscilloscope showing ignitor voltage traces for a good tube and a hard-starting tube.

Type 1*A* Weld Timer

The type 1*A* weld timer utilizes a small a-c contactor for controlling the ignitron contactor. The a-c contactor may be used to control directly the primary current of small welding transformers, provided the contact current rating is not exceeded. The elementary diagram of a typical timer is shown in Fig. 7-26. The circuit employs a vacuum timing tube (tube 1) and a thyratron control tube (tube 2) for controlling the relay *CR*. Although it is not necessary for the maintenance man to have a complete knowledge of the function of each individual circuit component, he should have a general knowledge of the circuit operation.

Timer Operation

In general, the type 1*A* weld-timer circuit consists of a vacuum tube or a thyratron tube (or both), a supply transformer, a relay, and a number of small resistors and capacitors. Timing or delay is usually accomplished by charging or discharging a capacitor. Most timers include a relay which is energized when the starting or initiating switch is closed. After a definite time interval, the relay is deenergized as the result of the timing capacitor charging or discharging. The relay coil is usually connected in the anode or power circuit of a tube, while the timing capacitor is connected in the grid or control circuit. Thus, with a relatively small amount of power in the grid circuit of a tube, we can control a large amount of power in the anode or plate circuit.

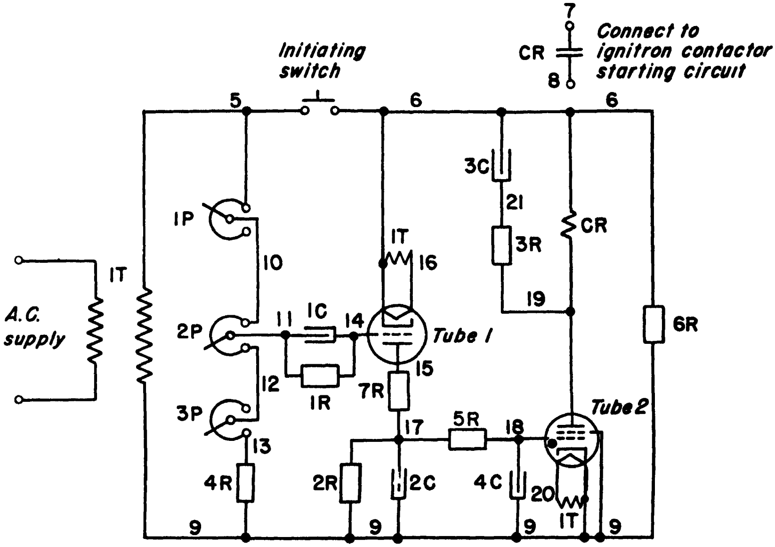


FIG. 7-26. Elementary diagram of a typical NEMA type 1A weld timer.

A capacitor to which a d-c voltage is applied suddenly acts as a short circuit the instant the voltage is applied. However, gradually the capacitor charges to a voltage equal to that applied and theoretically becomes an open circuit. This gradual change from a short circuit to an open circuit takes place during a definite time interval, depending on the voltage applied and the size of the capacitor. The larger the capacitor or the greater the voltage, the longer will be the time required to charge the capacitor. If the voltage and capacity remain the same, the time required for the capacitor to charge will always be the same.

If a capacitor is charged to a certain d-c voltage and then the supply voltage is suddenly removed, the capacitor will theoretically maintain the charge indefinitely. If a resistor is placed in parallel with the capacitor, the energy in the capacitor will dissipate in the resistor when power is removed. The time required for the capacitor to discharge is dependent upon the voltage, capacitor size, and size of resistor. In general, it is these principles, applied to the grid circuit of a tube, that are used in simple timing circuits.

The principal differences between the vacuum tube and the thyratron tube are twofold. First, the vacuum-tube plate current varies as the voltage on the grid is varied. Usually, the more negative the grid voltage, the lower is the plate current, while a more positive grid voltage produces a greater plate current. The thyratron passes no current in the plate or anode circuit when the grid is at a sufficiently negative potential. However, there is a certain point called the "critical grid voltage" (approximately 10 volts for most thyratrons) which, if the grid is made more positive than that value, will suddenly cause the tube to pass full load current with little resistance. The anode or plate current is determined by the load circuit and will remain the same regardless of how much more positive the grid is made. When a thyratron tube conducts—or, commonly, "fires"—a bluish glow will be present inside the tube. Second, all radio receiver-type vacuum tubes do not require a cathode heating period before being operated. The small thyratron tubes, such as the *GL*502*A* and *GL*2050, require a heating period of 10 sec before anode (or plate) voltage may be applied.

Testing

The two types of tubes used in the timer described above may be checked or tested in most receiver-type tube testers. An a-c voltmeter should be used to check the circuit voltage, while an ohmmeter should be used to measure resistance and check continuity. When making resistance measurements, disconnect the part being checked so as to avoid measuring a parallel circuit. When checking capacitors, remember that, although most capacitors short-circuit when they fail, the electrolytic types will often open-circuit and lose their capacity. The charging and discharging of capacitors may be observed with a cathode-ray oscilloscope. If trouble is experienced in the operation of this control, reference to Table X will be helpful in quickly locating the cause.

Timer Circuit Operation

In Fig. 7-26, the a-c voltage for heating the tube filaments is supplied with transformer $1T$. This same transformer also supplies the a-c voltmeter for the timing tube (1), control tube (2), and relay CR. During stand-by, the timing capacitor $1C$ is charged with a d-c voltage through grid rectification of tube 1. The charge on the capacitor will be negative at point 14, grid of tube 1. Capacitor $2C$ has no charge; therefore, the grid and cathode of control tube 2 are at the same potential. Being open, the initiating switch prevents an a-c voltage from appearing across tubes 1 and 2. As soon as the switch is closed, tube 2 will conduct and pick up relay CR. Tube 2 conducts almost immediately as the grid is at cathode potential and has no negative voltage to prevent the tube from conducting. The current in tube 1 is very small since the grid 14 is negative because of the charge on $1C$. Resistor $1R$ acts to discharge $1C$, at which time the current in tube 1 is increased. As the current in tube 1 increases, capacitor $2C$ is charged such that point 17 is negative with respect to 9. The result is that negative voltage is inserted in the grid circuit of tube 2. When this voltage reaches sufficient magnitude, it will act to shut off tube 2 causing relay CR to drop out and the welding current to terminate. The setting of potentiometer $2P$ determines the voltage to which capacitor $1C$ charges during stand-by. $1P$ and $3P$ are used to calibrate the range of $2P$ to agree with the dial setting.

Synchronous Control

Synchronous starting and continuous heat control are often incorporated in electronic resistance-welding controls to ensure uniform welds. Although it is possible to obtain a separate control to perform each of these operations, the type most commonly used with spot-welding controls consists of a single unit including the circuits of both.

To obtain consistent welding, especially when short timing intervals are used, it is necessary that each weld start at the same point in the current wave for each successive weld. If a welding machine is energized at any point in the current wave other than zero, a transient current will flow for the first few cycles. The magnitude of this transient will vary, depending upon the point in the wave at which the machine is energized.

Some welding machines employ a welding transformer with a tapped primary winding that can be used to obtain different weld currents.

This method of heat control limits the number of possible heat settings to the number of transformer taps. The electronic method of heat control is preferred since it provides a continuous range of heat settings.

Adjustment

The cathode-ray oscilloscope is *essential* not only for maintenance and servicing welding controls but also for properly making initial adjustments. Before operating a control for the first time, carefully read the instructions and wiring diagram accompanying the equipment. Very few forms of control can be installed without making one or more initial adjustments.

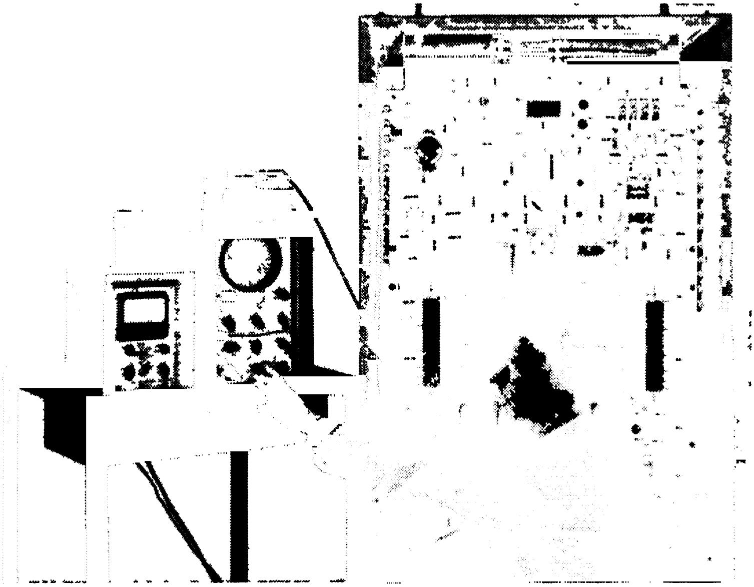


Fig. 7 27. Initial adjustments being made to welding control using cathode-ray oscilloscope and multimeter.

Synchronous spot-welding control without heat control usually requires a synchronous starting adjustment. Since each welding machine differs in power factor, the starting must be adjusted to meet the power-factor condition of the individual machine.

Panels employing heat control will require a full heat-limit adjustment which will also differ with the power factor of the welding machine. This adjustment involves setting a limit resistor, usually connected in series with the heat-control rheostat, so that full heat is obtained at the 100 per cent setting on the heat dial.

Use of Diagrams

Before attempting to maintain electronic welding controls, the serviceman should have a general knowledge of the complete circuit operation. The wiring diagram that accompanies each control will be found both useful and necessary in servicing this type of equipment properly. The diagram usually consists of an elementary circuit diagram and an actual wiring diagram. The elementary diagram is included to show the sequence of operation and to segregate the various circuits. In the case of the more complex controls, it would be almost impossible to identify the operation of the many circuits from the wiring diagram alone. For this reason, the actual wiring diagram should be consulted only when determining the physical location of circuit points that will be used in taking measurements or examining wave shapes. It should be remembered that on the elementary diagram the part symbols are located in the circuits in which they are used. The circuit points are connected together with the shortest possible lines and do not indicate the actual sequence of wiring.

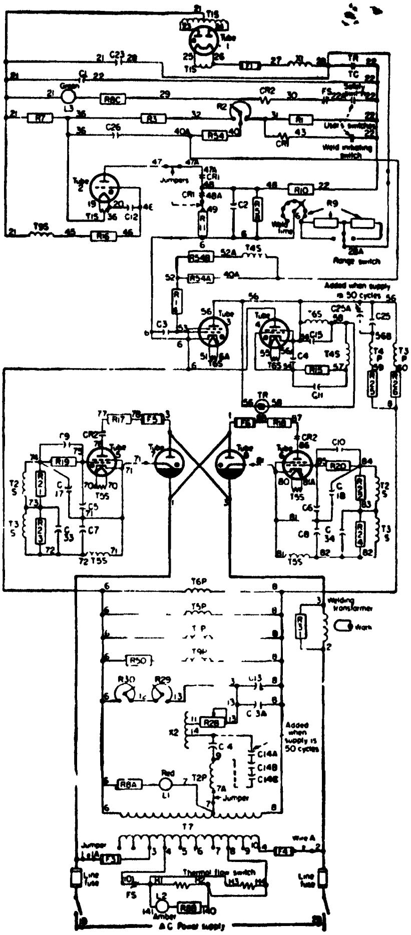


FIG. 7–28. Elementary diagram of a typical spot-welding control panel.

To start, one should familiarize himself with the elementary diagram of the control to be serviced. This diagram should be studied and the component parts that comprise the timing, synchronous starting, and heat-control circuits identified. Some diagrams are clearly drawn so that these circuits may be easily recognized; others require a little pencil and paper work to separate these circuits.

There are many different circuits used in welding controls, and to explain the operation of all of them would require much space. However, many of these controls use the same type of tubes and employ the same sequence of operation. In the following paragraphs the operation of a typical control (Figs. 7-28 and 7-29) is described.

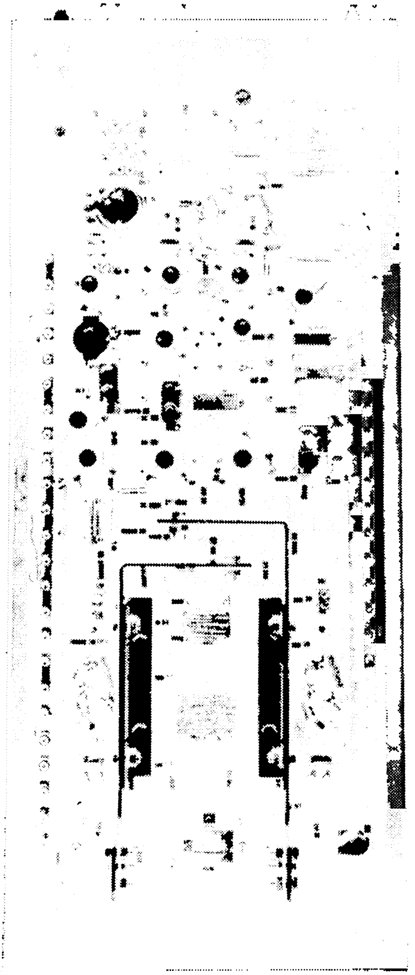


FIG. 7-29. Rear view of a typical spot-welding control panel.

Rectifier Circuit

Many timing circuits require a d-c voltage to obtain the timing action. This d-c voltage is usually obtained by means of a transformer, a rectifier tube, and a filter circuit, or by means of a transformer and a copperoxide rectifier. Faulty timing may result if some component of the rectifier circuit fails. A measurement of the d-c voltage with a voltmeter will usually indicate whether or not the rectifier is functioning properly. Also, it is a good policy to measure or examine the d-c voltage with a cathode-ray oscilloscope. The d-c output ot a filtered rectifier should appear as in Fig. 7-30. The deflection should be upward if the positive scope lead is connected to the plus and the negative lead to the minus side of the d-c supply.

A typical tube rectifier circuit is shown in Fig. 7-31. A center-tapped supply voltage is obtained with transformer T, which also has a filament winding for the heater of the rectifier tube. The filter circuit consists of the two capacitors (C and $1C$) and a reactor (X). A voltage divider made up of a number of resistors connected in series is usually connected across the d-c output. The purpose of the voltage divider is to divide the total d-c output into smaller voltages.

Timing Circuit

There are many forms of timing circuits used in the various electronic spot-welding controls. However, the most common circuits employ a capacitor and adjustable rheostat in the grid circuit of a vacuum or thyratron tube. The charging or discharging action of the capacitor is used to increase or decrease the grid voltage of the timing tube. Usually the grid circuit of a tube has a high impedance and is easily effected when voltmeters are connected to any part of the circuit. Since the cathode-ray oscilloscope has a high-impedance input circuit (having little or no effect on the grid circuit), it is advisable to use it in checking the timing circuit.

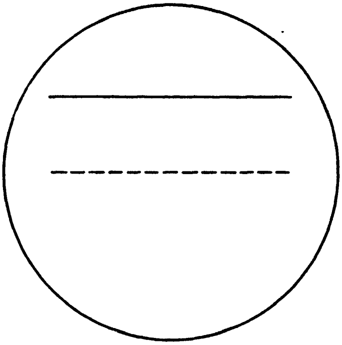


Fig. 7-30. Scope trace of d-c voltage.

A typical timing circuit operating from a d-c voltage is shown in Fig. 7-32. With the starting switch open, the cathode of the thyratron timing tube is connected through the timing rheostat to the positive side of the d-c supply. The grid is connected to a negative d-c potential and thus prevents the tube from conducting or firing. When the starting switch is closed, the timing capacitor and the cathode of the timing tube are suddenly connected to a point on the voltage divider more negative than the grid. In other words, the grid is now more positive than the cathode that permits the timing tube to conduct. The cathode side of the timing capacitor charges (through the timing rheostat) to the positive supply voltage. As the capacitor charges, the voltage of the cathode gradually increases until it is finally more positive again than the grid. This "sets up" the tube to cease conducting. Turning off the thyratron timing tube can be accomplished only when the anode voltage is at zero potential. Since the anode circuit is an a-c voltage, the tube will stop conducting when the anode voltage goes through zero. The negative grid (with respect to the cathode) will continue to keep the tube off until the starting switch is closed again. This fires the

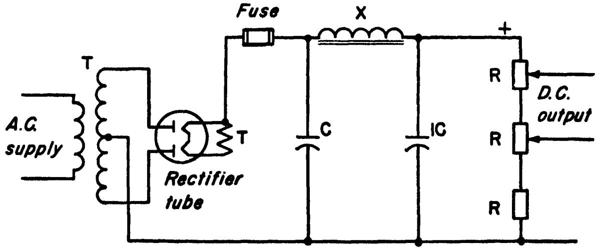


Fig. 7-31. Typical rectifier circuit.

tube as before, and the cycle repeats. The value of the timing resistance determines the time required for the capacitor to charge. The greater the resistance, the longer will be the timing interval.

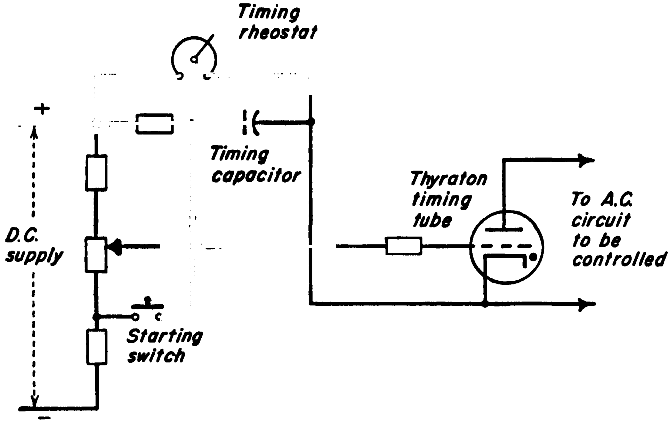


FIG. 7-32. Typical timing circuit.

Erratic timing is usually the result of failure of the timing tube or some part in the timing circuit. In many instances, the timing rheostat will become open-circuited because of excessive wear, and this results in a very long timing. Failure of the d-c supply will also cause continuous firing of the timing tube.

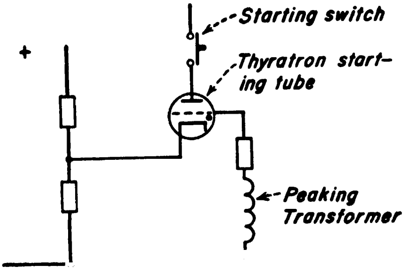


FIG. 7-33. Typical starting circuit.

Starting Circuit

As stated before, to ensure uniform welding, it is necessary to start the timing interval at the same instant for each weld after the starting switch is closed. This may be accomplished by connecting a thyratron tube in series with the starting switch. A typical starting circuit is shown in Fig. 7-33. Closing the starting switch applies a d-c voltage to the anode of the starting tube. The grid of the tube is held negative by a voltage from the voltage divider. For this reason the tube will not conduct.

A peaking transformer in the d-c grid circuit inserts a peaked voltage on the grid of the starting tube. This transformer is of special design and gives a peaked voltage output which might appear as shown in Fig. 7-34 when viewed with an oscilloscope. Since the grid already has a negative d-c voltage, the total grid voltage on the starting tube will appear as shown in Fig. 7-35. From this it will be noted that for an instant the grid is driven positive. It is at this instant that the starting tube is fired and timing is started. The positive peak will always appear at this same instant with respect to the supply voltage and thus start the timing at this same point, regardless of when the starting switch is closed.

Failure of the starting tube will usually prevent the starting switch from initiating the control. Complete failure or partial failure of the peaking transformer will prevent the starting tube from initiating the timing circuit. On controls with heat control, the phase setting of the peak voltage is fixed. However, controls without heat control require adjusting the peak to the power factor of the welding machine. Improper adjustment of this peak voltage will result in transient currents during the first few cycles of weld current.

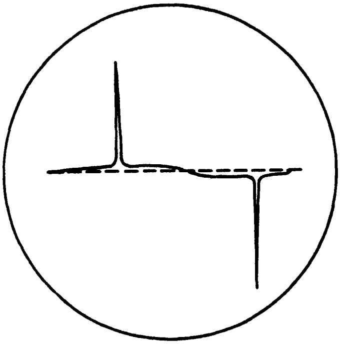


FIG. 7-34. Impulse or peak-voltage scope trace.

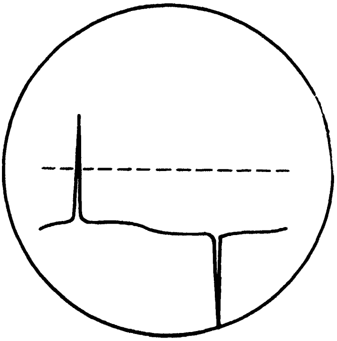


FIG. 7-35. Scope trace showing peak voltage superimposed upon a negative d-c voltage.

Trailing Circuit

The thyratron tube passes current in only one direction and only in that interval during which the anode is positive with respect to the cathode. Therefore, a thyratron tube when used on a-c voltages will pass current only for the positive half-cycles during which the anode is positive. In welding control circuits where a-c voltages are used almost exclusively, it is necessary to use two thyratron or ignitron tubes in each circuit in order to pass a full sine-wave a-c current. An inverse parallel connection is made by connecting the anode of each tube to the cathode of the other, as in Fig. 7-36. This connection commonly called "back to back" permits one tube to pass current in one direction and the other in the opposite direction.

The additional tube that is connected in inverse parallel with the timing tube is called the "trailing tube," because for each half-cycle that the timing tube conducts, the trailing tube will conduct for the corresponding negative half-cycle. In Fig. 7-36, the inverse parallel connection of the thyratron tubes is used to fire or energize the two transformers 3*T* and 4*T*. Transformer 3*T* supplies the a-c "turn-on" voltage to the firing tubes while 4*T* supplies a turn-on voltage for the trailing tube. The grid circuit of the trailing tube is made up of a self-rectified bias voltage, hold-off voltage 6*T*, and a turn-on voltage 4*T*. The self-rectified bias is accomplished with a small resistor and capacitor connected in parallel, and is used to force the grid voltage negative slightly before the anode becomes positive. The hold-off voltage which normally prevents the tube from firing is supplied through transformer 6*T* from the a-c supply. The secondary of this transformer is connected such that the voltage is 180 deg out of phase with the trailing-tube anode voltage. Transformer 4*T* primary is connected in series with a capacitor so that the voltage lags from the first half-cycle of the timing-tube conduction. This voltage is transformed to the grid of the trailing tube with a polarity that will make the grid become positive and cause conduction during the subsequent half-cycle. By this means, the trailing circuit provides a timed sine-wave voltage to transformer 3*T*. The secondary leads of 3*T* are connected to the grids of the firing tubes.

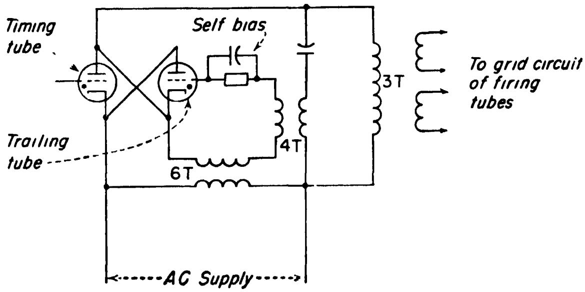


FIG. 7-36. Typical trailing circuit.

Loss of the supply voltage will prevent the timing and trailing tubes from conducting. Failure of the trailing tube or turn-on transformer 4*T* will result in failure to fire the corresponding firing tube. This will prevent one power tube from conducting, resulting in supplying half-cycles to the welding transformer. These half-cycles will be of the same polarity and will cause a d-c component to flow in the primary of the welding transformer. This d-c component will cause the transformer iron to saturate (indicated by a growling noise) and will eventually trip the line circuit breaker. The effects are the same with panels not having heat control since the timing and trailing tubes also act as the firing tubes.

The firing tubes are used to cause the ignitrons to pass current for the time-interval setting of the timing circuit. These tubes may also be used to delay the firing of the ignitron tubes and thus provide heat control. This requires a separate thyratron tube to fire each ignitron tube. The grid circuit of each firing tube is identical except that each is operating 180 deg out of phase with respect to the other. Each grid circuit usually consists of a hold-off bias voltage and a timed turn-on voltage. The hold-off bias may be an a-c sine wave or d-c voltage, while the timed turn-on voltage may be a pulse, sine wave, or d-c voltage. If heat control is employed, a phase-controlled sine wave or pulse voltage may be used to delay the firing of the tube. Other forms of heat control may employ a variable d-c voltage.

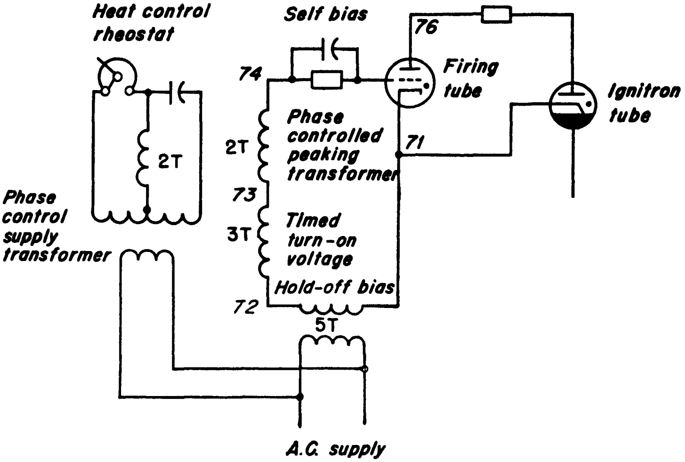


FIG. 7-37. Typical firing circuit.

A typical firing circuit is shown in Fig. 7-37. The grid circuit consists of a self-rectified grid-bias voltage, a-c sine-wave hold-off bias voltage, timed a-c sine-wave turn-on bias, and a peaked phase-controlled voltage. The self-rectified bias is obtained with a resistor and capacitor connected in parallel. The hold-off bias is supplied through transformer $5T$ from the a-c line. This voltage is 180 deg out of phase with respect to the anode voltage of the firing tube. The timed turn-on voltage $3T$ is supplied from the timing circuit just described (see Fig. 7-36). The phase-controlled peak voltage $2T$ (heat control) is supplied from the phase-shift circuit consisting of the center-tapped phase-control supply transformer with rheostat and capacitor.

With the positive lead of an oscilloscope connected to the anode (point 76 in Fig. 7-37) of the firing tube and the negative lead connected to the cathode (point 71), a single sine wave may be synchronized, as in Fig. 7-38. This indicates that the anode of this tube is positive during the first half-cycle. If the *positive* scope lead is moved to the grid side of 5*T* (point 72) with the negative lead remaining at the cathode (71), the hold-off bias will appear as shown in 7-39. This shows that, while the *anode is positive* during the first half-cycle, the *grid is negative.* In using the oscilloscope for such tests, the positive lead should always be connected nearest the grid side of the voltage to be measured. This makes it possible to compare the grid voltage to the anode voltage which has been set up as a reference. If the timed turn-on voltage (across points 72–73) is examined, it will appear as the dotted sine wave in Fig. 7-40. The solid line in this figure represents the 5 per cent hold-off bias.

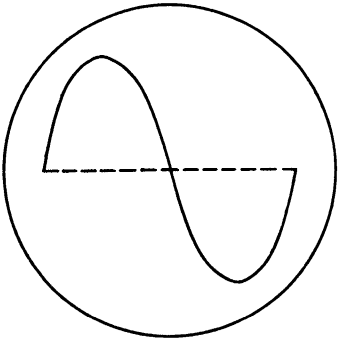


Fig. 7–38. Scope trace of a-c sine-wave voltage.

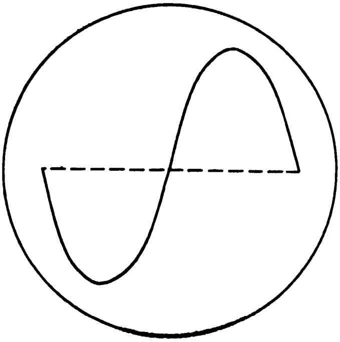


Fig. 7–39. Scope trace of a-c sine-wave voltage 180 deg out of phase with that in Fig. 7-38.

Comparing the two voltages, it is easy to recognize that the purpose of the turn-on voltage is to cancel out part of the hold-off voltage during the timing period. During stand-by, the total grid voltage measured from the cathode side of the self-rectified bias (point 74) to the cathode (point 71) will appear as in Fig. 7-41. The peak voltage may be shifted along the 5*T* hold-off voltage by varying the heat-control rheostat in the phase-shift network supplying power to 2*T* transformer. During timing, 3*T* voltage cancels out enough of the 5*T* voltage to allow peak from 2*T* to fire the tube. The phase setting of this peak determines the phase angle at which the firing tube will start conduction and thereby control the point in the cycle at which the ignitron power tubes fire. A maximum of full heat is obtained with the rheostat set so that each power tube passes current during its full half-cycle. Any less amount of heat can be obtained down to 20 per cent by adjusting the rheostat to delay firing the power tube so that it passes current during only part of the half-cycle when its anode is positive.

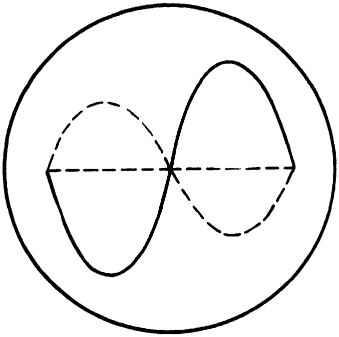


Fig. 7–40. Scope trace showing phase relationship between two grid voltages.

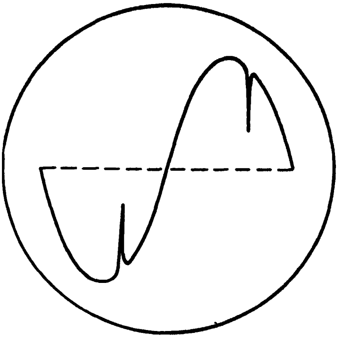


Fig. 7–41. Scope trace of a-c sine wave and a peak voltage.

If, because of failure of the timing and trailing tubes, a turn-on voltage is not supplied by 3*T*, the firing tubes will not conduct. Failure of hold-off bias 5*T* will result in both firing tubes conducting continuously. A defective peaking transformer 2*T* will result in failure of the firing tubes to conduct when a timing turn-on voltage is supplied by 3*T*. The heat-control action may be checked by measuring the voltage drop across the firing tubes. This is accomplished by placing the positive scope lead on the anode and the negative lead on the cathode of the same tube. At 100 per cent heat setting, the voltage should appear as the solid line in Fig. 7-42 while at a reduced heat (approximately 50 per cent) as shown in Fig. 7-43. The dotted sine wave is that voltage which appears across the tube during stand-by.

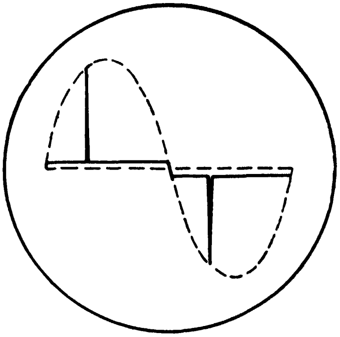


Fig. 7–42. Voltage drop during 100 per cent conduction (full heat).

By examining the voltage between the anode and the cathode of a tube passing welding current, it is possible to measure the phase angle of the load current, determine the arc drop of the tube, and determine that portion of the cycle during which conduction takes place. Referring to Fig. 7-44, the dashed line represents the anode voltage of two tubes, *A* and *B*, connected in inverse parallel. The solid line represents the arc voltage which is viewed during 100 per cent conduction. The point at which one tube goes out and the other starts to conduct is represented by a reverse in arc voltage. It is at this point that the current (indicated by dotted line) passes through zero. By measuring the difference between voltage zero and current zero, the power factor of the load may be determined. Since a full cycle is 360 deg, the angular lag of the current is found to be approximately 60 deg (Fig. 7-44). The cosine of this angle is the power factor of the load (approximately 0.5).

Servicing

It is important to have the proper instruments available at all times if prompt repairs are to be made to electronic welding controls. A cathode-ray oscilloscope, volt-ohmmeter, tube tester, miscellaneous spare parts, and tools may be kept on a small cart similar to that shown in Fig. 7-27. In case of trouble, the cart can be easily wheeled to the machine requiring service and used conveniently where it is needed.

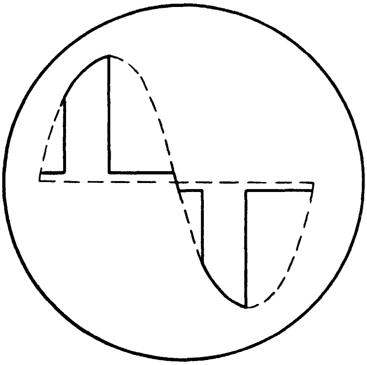


FIG. 7-43. Voltage drop during partial conduction (low heat).

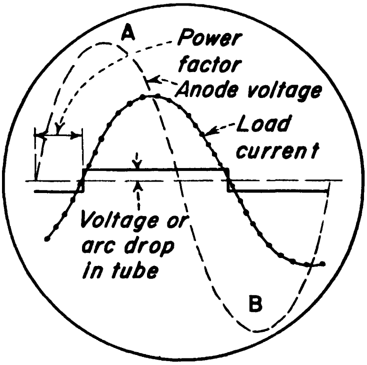


FIG. 7-44. Voltage across tubes during 100 per cent conduction to a welding load

The ability of the serviceman to localize trouble will greatly reduce the servicing time during breakdowns. By segregating and studying the various individual circuits, the serviceman can gain a practical understanding of all the electronic welding control circuits in his care. Although Table XI is for a control employing the circuits already discussed (Figs. 7-28 and 7-29), it provides the fundamental pattern to follow in approaching servicing problems of similar circuits in any type of electronic equipment.

ELECTRONIC RESISTANCE-WELDING CONTROL

Installation Tips:

1. Mount control in a clean, accessible location; one free from excessive vibration and yet as near as possible to the welding machine.
2. Use conduit wiring throughout.
3. Connect equipment to a bus having the best regulation.
4. Ground all frames and enclosing cases.

5. Use clean water for cooling electronic tubes.
6. If separate supply is used for control power, be sure to maintain same phase relationship with main power.
7. Read all instructions and diagrams which accompany panel.
8. Locate a weld/no-weld (or protective switch) on welding machine convenient to operator. Check panel wiring diagram for proper circuit in which switch should be connected.
9. Be sure to allow necessary preliminary heating on all the larger mercury-type hot-cathode tubes.
10. Keep a service record of each control and all tubes contained in the control

Servicing Tips:

1. Make Safety First the rule when working on controls with power applied.
2. From the action of the control, try to confine fault to a particular circuit.
3. Check tubes by inserting tubes known to be good, or by exchanging a questionable tube with another similar tube in the control.
4. Examine control for smoking or burned parts.
5. Check all fuses.
6. Check action of all relays and interlocks. Keep contacts clean.
7. When taking measurements or working on control with power applied, remove ignitor fuses to avoid energizing welding transformer.
8. Measure a-c sine-wave and d-c voltages with a reliable voltmeter.
9. Examine timing and pulse or peak voltage with a cathode-ray oscilloscope. Be sure scope has been properly modified to read d-c voltages.
10. Avoid connecting voltmeters or oscilloscopes directly to the grid of a thyratron tube.
11. When checking resistors and capacitors, be sure to isolate them from other circuits.
12. Check movable or adjustable switches, resistors, or capacitors for worn or dirty contacts.

Seam-welding Control

Seam welding proved to be the solution to a great many production problems during the war. As one example, there was a great demand for air- and water-tight metal cylinders. Many of these, such as gas tanks were fabricated from sheet metal. The seams of these containers were welded together with electronically controlled resistance seam-welding machines (Fig. 7-45). This method of fabrication proved a dependable and speedy means of producing these parts which were so vital to the war effort. For this reason, many factories have installed a large number of seam-welding controls and machines. The maintenance of this type of control is much the same as the spot-welding controls, although the timing circuits are more complicated and require more study.

Time Cycle Electronically Controlled

A seam-welding control is used to produce a series of spot welds. The spacing between each spot weld is determined by the speed of the roller type electrodes and the time interval between welds. The electrode speed is usually controlled by means of a variable-speed motor drive. The time interval during welding (usually referred to as "heat" time) and the time between welds (usually referred to as the "cool" time) are electronically controlled on modern seam-welding machines. The power and firing circuits are very similar to those used in electronic spot-welding controls. Originally, a mechanical timing disk or chain was used in the timing circuits of the first electromechanical-type controls. Newer controls have been designed completely electronic.

FIG. 7–45. Seam welder makes gas-tight seams at the rate of 60 in. per min.

Electromechanical Timing

The electromechanical seam-welding control consists of a motor-driven chain, or disk made up of conducting and nonconducting buttons or segments. A synchronous motor drive is used to maintain synchronism with the supply voltage. Each button of the chain usually represents one cycle or one half-cycle timing. The correct seam-weld pattern is set up by locating the buttons in the desired sequence. A typical chain-type seam-welding control is shown in Fig. 7-47.

The chain-type seam-welding control employs a brush mechanism which is connected in series with the primary of a transformer energized from the supply voltage. Each time a conducting button passes the brush, this transformer is energized for one cycle (Fig. 7-48). This transformer has two secondaries, one being connected into the grid circuit of each of the firing tubes, each winding supplying the timed sine-wave turn-on voltage to the grids of the tubes. Like all mechanical devices, the brush and buttons are subject to wear and will occasionally require adjustment. The position of the brush must be adjusted so as to give smooth commutation. This is accomplished by examining the voltage across the secondary of the turn-on transformer with a cathode-ray oscilloscope. The brush should be adjusted with a one- or two-cycle weld or heat-time pattern. The cool time is not important. By synchronizing the oscilloscope with the

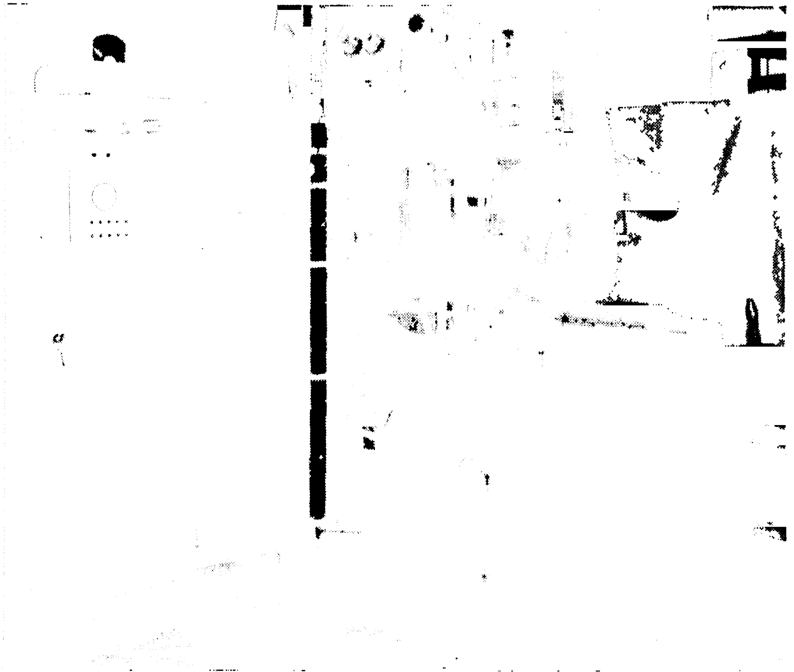


FIG. 7-46. Typical seam-welding installation setup for welding metal-envelope electronic tubes.

supply voltage to give a steady three- or four-cycle pattern, improper commutation will be indicated by a voltage pattern on the secondary of the transformer similar to that in Fig. 7-49*A*. With the correct

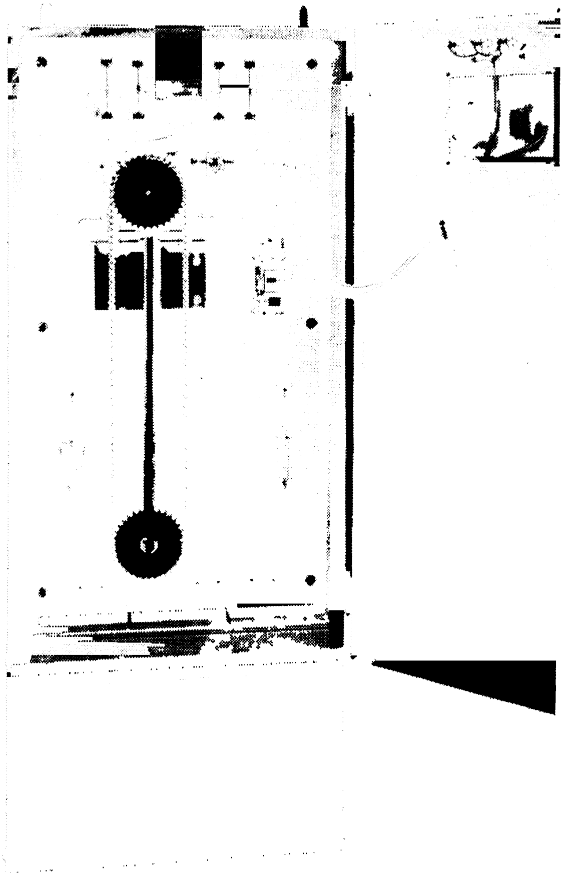


FIG. 7-47. Typical chain-type thyratron seam-welding control panel.

location of the brush, electrical contact is made at the zero point in the voltage wave and the voltage will appear as in Fig. 7-49*B*.

The heat-control circuit is similar to that of the spot-welding control. The full-heat limit resistor must be adjusted to give full heat at 100 per cent dial setting. This adjustment is similar to that described under "Spot-welding Control."

Electronic Timing

In the completely electronic seam-welding control, the mechanical timing circuit is replaced with electronic tubes (Fig. 7-50). The time settings may be changed by merely operating a switch or turning a dial while the mechanical timer requires rearranging of the buttons or segments to give the desired heat and cool times.

Timing Circuit

Similar to the spot-weld timing circuit, the seam-weld timing circuit usually operates from a d-c voltage. This voltage, obtained by rectifying the a-c line voltage, may be easily checked with a d-c voltmeter. The seam weld, being a series of heat and cool times, usually requires two separate timing circuits, one for the heat time and the other for the cool time. Although these circuits may be identical, they are interconnected in such a manner that the termination of timing of one causes the other to be initiated. This seesaw action continues as long as the initiating circuit remains closed.

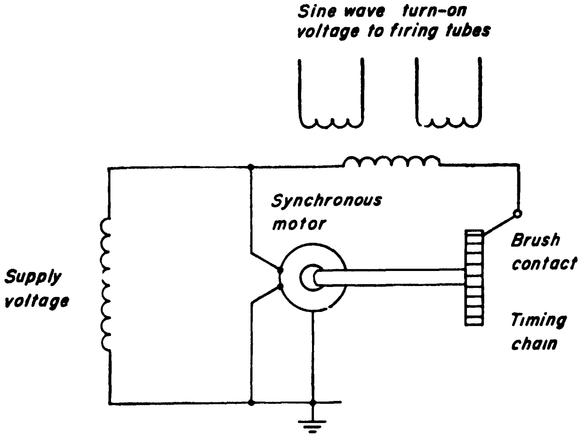
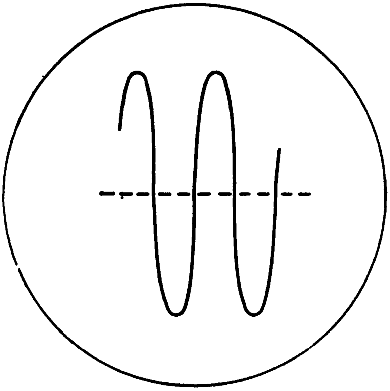


FIG. 7–48. Elementary diagram of chain-type seam-weld timing circuit.

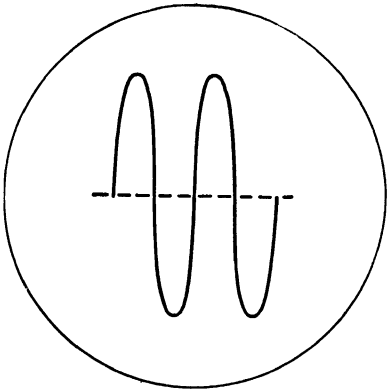
A typical inverter timing circuit is shown in Fig. 7-51. The circuit includes two thyratron tubes and a vacuum tube. Tube 10 conducts during the cool time while tube 9 conducts during the heat or weld time. With the initiating switch open, tube 9 has no anode voltage. However, tube 10 becomes conductive as soon as the d-c voltage is applied. As long as the initiating switch remains open, tube 10 will continue to pass current. Capacitor $C2$ charges positive at 40 and negative at 45. Timing capacitor $C3$ charges positive at 40 and negative at 43 through the vacuum diode tube 2. The inverter circuit remains in this state until the initiating switch is closed, at which time tube 9 immediately conducts pulling point 40 down to 36. By virtue of the charges on capacitors $C3$ and $C2$, the anode and grid of tube

10 are driven negative with respect to the cathode 36, causing tube 10 to stop conducting.

The time constant of *C*2 and *R*5 is such that *C*2 discharges within a fraction of a cycle, thus returning the anode of tube 10 to a positive potential. The time constant of the grid circuit is determined by capacitor *C*3 and resistor *R*36. The resistor *R*36 being variable, enables the operator to vary the time constant of this circuit and thus vary the time required for the grid of tube 10 to return to a potential approximately equal to 36, and once again fires tube 10. The firing point in the cycle of tubes 9 and 10 is accurately controlled with a peak voltage imposed on the grid circuit of these tubes by transformer *T*3.



A- Improper commutation



B-Correct commutation

FIG. 7–49. Scope traces showing improper and correct commutation of electromechanical timer.

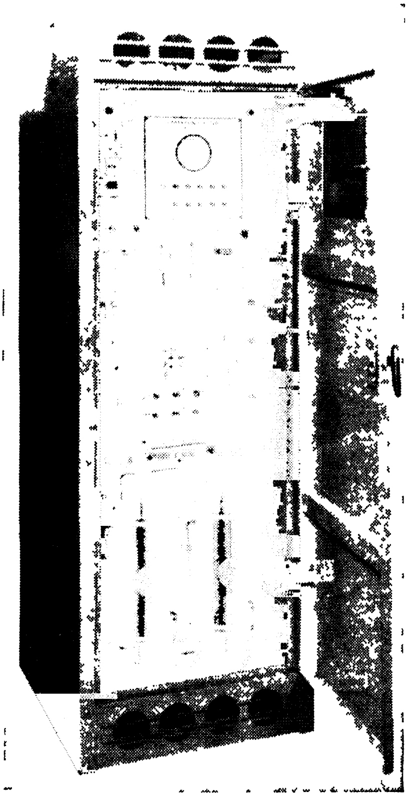


FIG. 7-50. An all-electronic seam-welding control. Note the two thyratrons which conduct individually and alternately during the preset heat and cool times.

If the initiating switch remains closed, the action of tube 10 firing will be similar to above. By virtue of the charge on capacitors $C2$ and $C4$, the anode and grid of tube 9 will be driven negative, causing tube 9 to stop firing. The anode of tube 9 will return to a positive potential within a fraction of a cycle. However, the action of the grid is controlled by the time constant of capacitor $C4$ and resistor $R35$. The time range of the variable resistors $R36$ and $R35$ is usually 1 to 30 cycles.

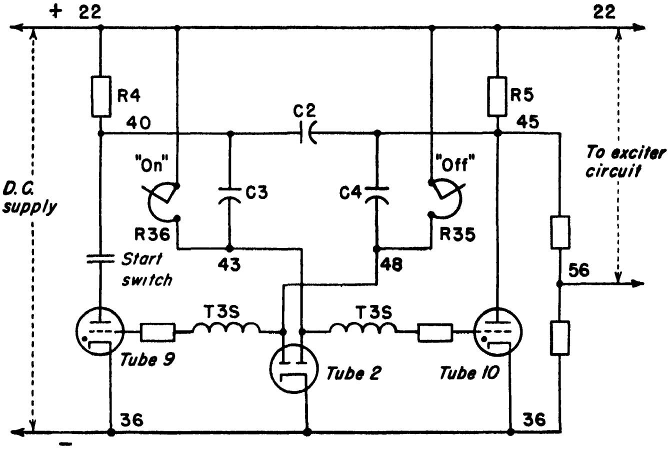


FIG. 7–51. Inverter timing circuit for electronic seam-welding control shown in Fig. 7–50.

A voltage divider is placed across tube 10 such that a d-c voltage may be inserted in the exciter circuit. This voltage is almost a square wave because of the action of tube 10. When tube 10 is conducting, the voltage between 22 and 56 is in the order of several hundred volts. However, when tube 10 is prevented from conducting (during the heat time), this voltage is reduced to approximately a tenth of that value. Thus, during the heat time the d-c voltage 22-56 is low, and during the cool time it is comparatively high. During a one-cycle heat and one-cycle cool seam-weld the voltage 22-56 will appear as in Fig. 7-52.

Exciter Circuit

The purpose of the exciter circuit is to supply a turn-on voltage to the firing tubes which is timed by the timing circuit. Also it is possible to introduce phase or heat control in this circuit. The typical exciter used with the described timing circuit consists of two thyratron tubes controlling the energy supplied to an impulse or peaking transformer. (Fig. 7-53).

The inverter or timing circuit voltage 22-56 is connected to the grids of the exciter tubes. Imposed in the grid circuits is a phase-controlled peak voltage *T2S* (heat control). Similar to the spot-welding control, this phase shift is accomplished with a resistor and capacitor from the supply voltage. During the cool time, the d-c voltage from the inverter is of such a magnitude that the peak will not allow the exciter tubes to fire. However, during the heat time this voltage is reduced to allow the peaks to cause conduction. The exciter tubes during the heat time energize *T*6 transformer from supply transformer *T*4. This excitation takes place in such a manner that impulse transformer *T*6 produces sharp peaks of the same polarity. This method of "shock" excitation also enables the phase relationship of these peaks to be controlled by the firing point of the exciter tubes, which is controlled by peak voltage *T*2 in the grid circuit of the exciter tubes.

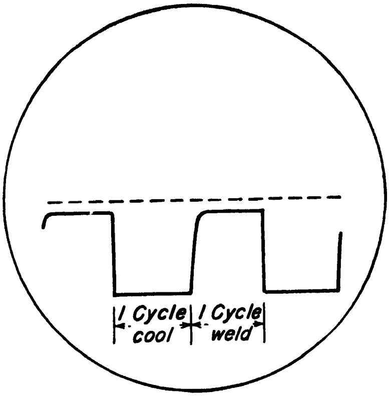


FIG. 7-52. Scope trace of a one-cycle heat one-cycle cool seam-weld voltage setting.

Firing Circuit

The firing circuit is employed to cause ignition of the ignitron tubes Similar to the spot-welding control, a thyratron is used to control or fire each ignitron. The circuit of each firing tube is usually identical except that each is operating 180 deg out of phase with respect to the other.

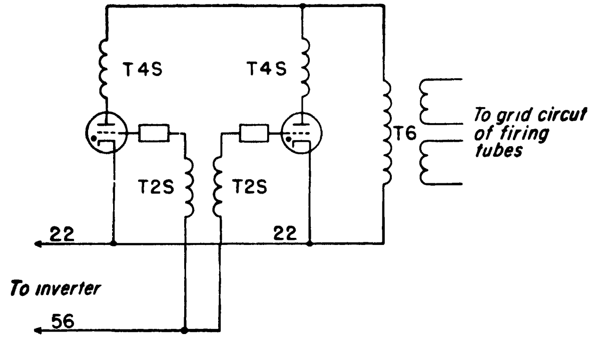


FIG. 7-53. Elementary diagram of an exciter circuit operated from an inverter-type timing circuit.

A typical firing circuit used with the above exciter and timing circuits is shown in Fig. 7-54. The grid voltage consists of the self-rectified bias derived from resistor and capacitor *R*19 and *C*7, a-c hold-off bias *T*5*S*, and the impulse turn-on voltage *T*6*S*. During the cool time no impulse is produced in *T*6*S*. However, during the heat time, a phase-controlled peak appears for the desired timing period and heat setting. The presence of this peak in the grid circuit of the firing tube causes conduction, which fires the corresponding ignitron or power tube.

The elementary diagram for a complete seam-welding control using the circuits described is shown in Fig. 7-55. Although all seam-welding controls are not alike, the breakdown of the circuits in a manner similar to that described will be found very helpful in servicing other types of welding controls.

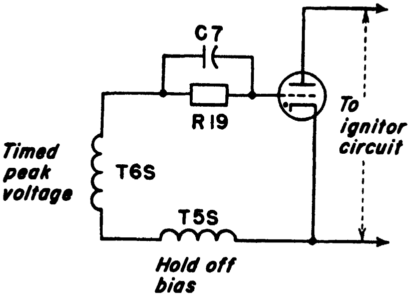


FIG. 7-54. A typical firing circuit used with exciter and timing circuits of all-electronic seam-weld control.

Servicing

The method of servicing a seam-welding control is very similar to that of the spot-welding control. Table XI may be used when servicing this type of seam-welding control equipment. When checking or calibrating the timing of a spot-welding control, it is necessary to use a cycle counter or recorder. However, in the case of a seam-welding control where the heat and cool times are repetitive, an oscilloscope may be used to advantage.

Calibration

Almost all forms of electronic seam-welding controls have calibration potentiometers mounted in the back of the control panel. These potentiometers are adjusted at the factory and usually are locked in position with some form of locking nut. If, because of failure of some part in the timing circuit, it is necessary to change a resistor, capacitor, or transformer directly associated with the timing action, it is a good policy to check the calibration of the heat and cool time dials. This may be done with a reliable cycle counter or recorder, although accurate timing may be accomplished with a cathode-ray oscilloscope. Although the counters and recorders are direct reading, they are subject to error. An oscilloscope is exact and easy to read.

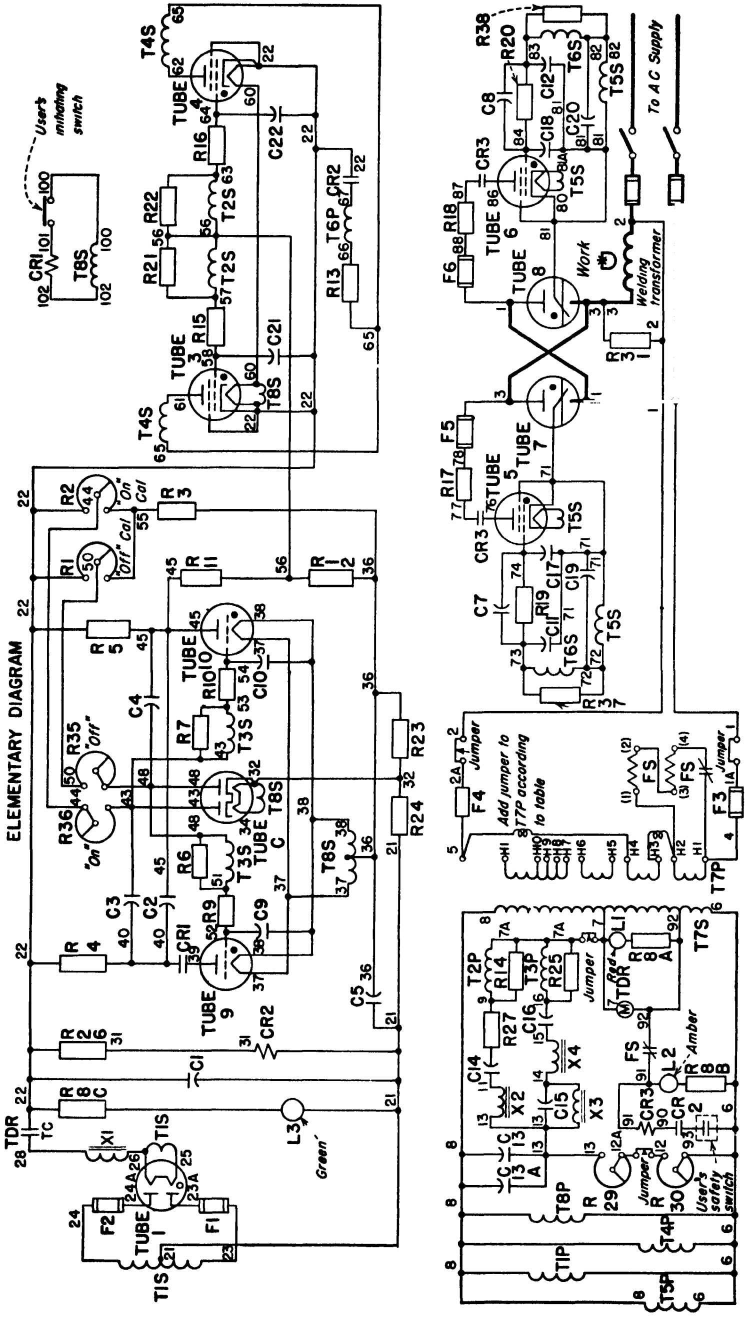


Fig. 7-55A. Elementary diagram for a complete seam-welding control.

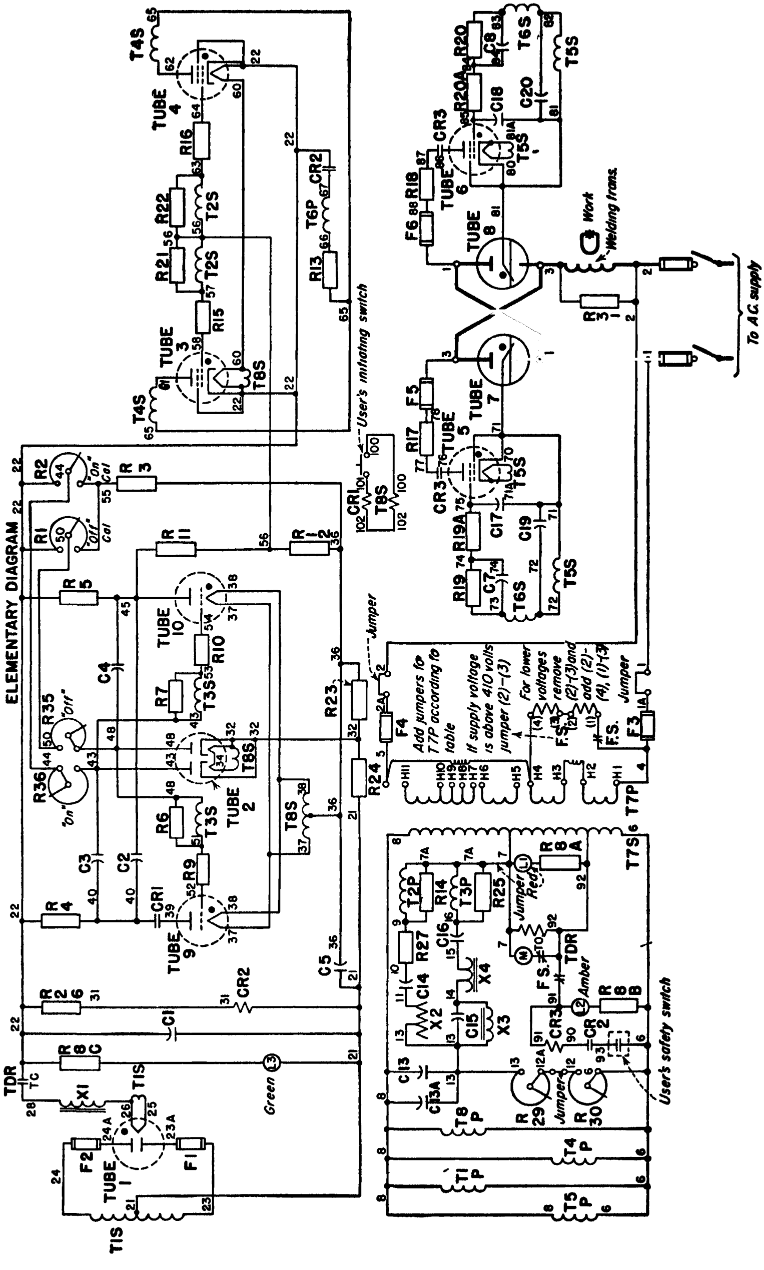


FIG. 7-55B. Elementary diagram for a complete seam-welding control.

It is important that it should have a sweep circuit slow enough to permit synchronizing at least six cycles on the screen before the instrument can be used easily to calibrate timing ranges up to 30 cycles. With this method, the heat and cool times are calibrated separately, and it makes no difference which is calibrated first. In those controls using a time sine-wave turn-on voltage, it is convenient to examine this voltage during calibration. Because all controls do not employ this method, the following description and illustrations are based on examining the voltage across the firing tubes, which is the same regardless of the timing circuit employed. In order to distinguish easily between the heat and cool time, it is suggested that the control be operated at 100 per cent heat setting. The oscilloscope leads should be connected to the anode of each of the firing tubes, and six cycles synchronized on the screen of the oscilloscope to look like Fig. 7-56. Placing a copper bar between the electrodes of the welding machine will save material and give proper loading to the machine during calibration.

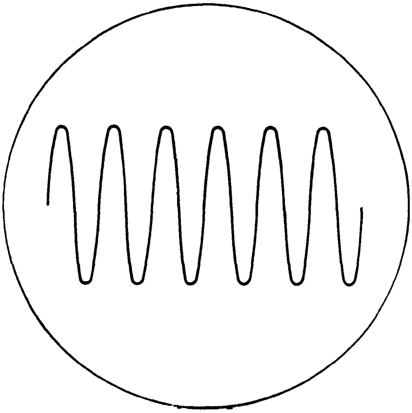


FIG. 7-56. Scope trace showing six cycles synchronized on screen.

First, the lower timing settings should be checked by actually observing and counting the number of cycles on the screen. One cycle heat and one cycle cool will appear as in Fig. 57. The cycle during welding is indicated by the straight line or tube drop during conduction. The OFF time is indicated by the sine-wave voltage and indicates that the firing tubes are not conducting. Three cycles heat and three cycles cool should appear as in Fig. 7-58, while two cycles heat and one cycle cool and one cycle heat and two cycles cool should appear as in Figs. 7-59 and 7-60, respectively.

It should be noted that the timing pattern will be steady and the heat time will appear at the same point on the screen after each OFF time. An unstable pattern will indicate that the panel is out of calibration. On these low time settings, it is easy to observe which one, or if both times are out of calibration. As long as the sum of the heat and cool times is equal to 6 or divisible by 6, a synchronous pattern can be directly observed on the screen of the oscilloscope. In order to check timing combinations such as 4 and 1, or 2 and 3, it is necessary to synchronize five cycles, instead of six cycles on the screen. If time settings such as 4 and 1, or 2 and 3 are examined on a six-cycle pattern, the position of the heat and cool times will not synchronize and appear to dance about, making it impossible to determine the exact timing and consistency of the heat and cool time intervals. With a five- or six-cycle pattern, it is possible to check all combinations from one cycle heat and five cycles cool to five cycles heat and one cycle cool.

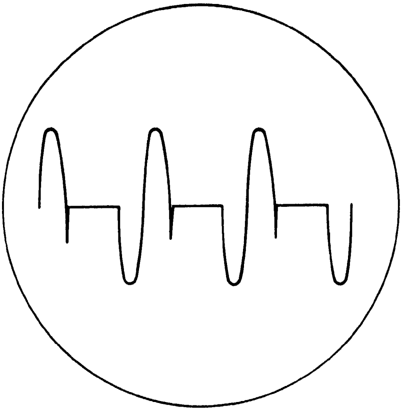


FIG. 7–57. Scope trace shows one cycle heat and one cycle cool time.

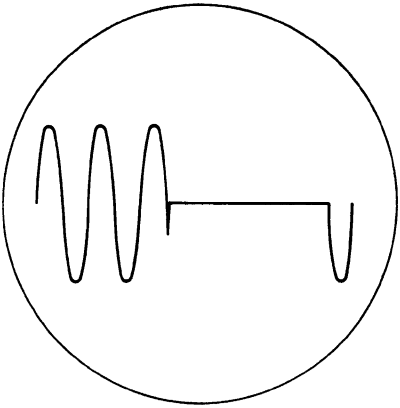


FIG. 7–58. Scope trace shows three cycles heat and three cycles cool time.

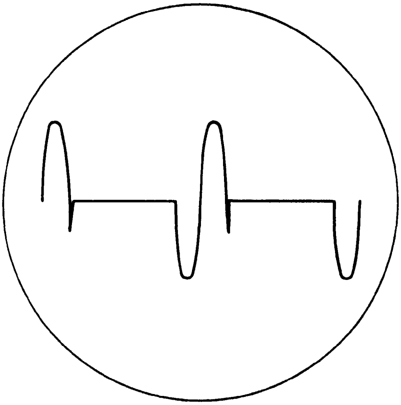


FIG. 7–59. Scope trace shows two cycles heat and one cycle cool time.

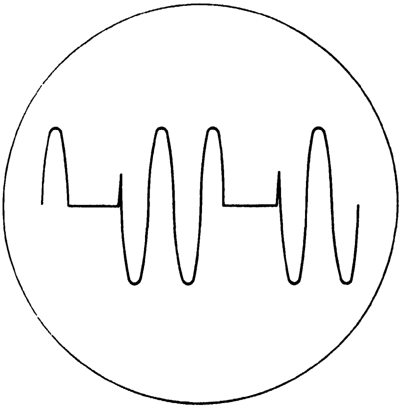


FIG. 7–60. Scope trace shows one cycle heat and two cycles cool time.

Calibrating Longer Time Ranges

The design of most timing circuits is such that the lower dial settings remain in calibration regardless of the calibration potentiometer setting.

Assuming that the lower time settings have been checked on both the heat and cool time dials and found to be in calibration, the next step is to check the longer time settings. When calibrating the longer timing ranges, it is important to set the time range dial not being calibrated at some low setting, such as one, two, or three cycles. These low settings which have already been checked are easily viewed on a five- or six-cycle pattern on the scope.

If the sum of the heat and cool times is divisible by the number of cycles synchronized on the screen of the oscilloscope, a steady wave form of the shorter time will appear, provided the longer time is in calibration. If the shorter time appears to dance about, the calibration of the longer time should be adjusted to produce a steady state.

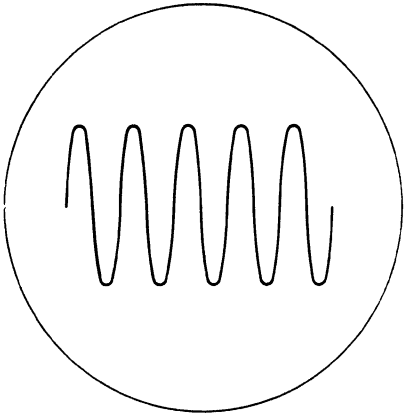


FIG. 7-61. Scope trace showing five cycles synchronized on screen.

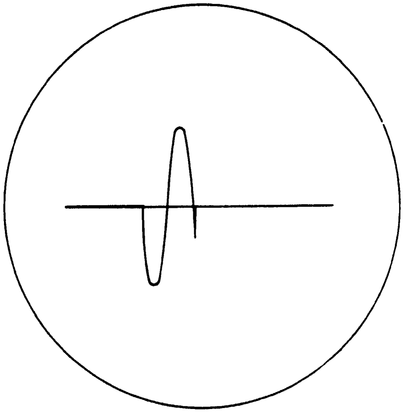


FIG. 7-62. Scope trace shows 29 cycles heat and one cycle cool time on a screen synchronized at five cycles.

If the control is set at 1 cycle heat and 29 cycles cool, the sum of the times is equal to 30, which is divisible by 5 or 6. Assuming that the oscilloscope is adjusted for a five-cycle pattern, a steady wave form should appear on the scope. There may be some question as to whether this is 1 cycle heat and 19, 24, 29, or 34 cycles cool, as all of these settings, divisible by 5, would give a steady wave form. A check can be made by switching to a six-cycle pattern on the scope. If a steady wave form is still observed, the timing is 1 cycle heat and 29 cycles cool as the total 30 is divisible by both 5 and 6, while the total of the others is not. In a similar manner, settings such as 2 cycles heat, 28 cycles cool, 3 cycles heat, 27 cycles cool, or 4 cycles heat, 26 cycles cool may be checked. In calibrating the ON time, the procedure is the same except that the OFF time is set at the short time and observed on the screen in a similar manner.

Most electronic timing circuits are so constructed that if calibration is adjusted at the longer time settings, all the lower settings will be in calibration. It is a good policy, however, to spot-check some of the shorter time settings to ensure complete calibration. Table XII will be helpful in selecting time settings which should produce steady wave forms if the control is in calibration.

The oscilloscope method of checking the timing of a seam-welding control may seem rather lengthy and complicated at first; however, facility comes with practice. Servicemen familiar with this method prefer it to the other means of checking timing.

TABLE IX.—SERVICE CHART FOR IGNITRON CONTACTORS

Trouble	Cause	Test
1. Ignitron contactor does not pass current to welding machine when initiating switch is closed (see Fig. 7-21).	*a.* Line fuse blown.	Remove fuses and test with ohmmeter, or check fuses in box using test lamp or indicator.
	b. Ignitor fuse blown.	Remove fuse and test with ohmmeter.
	c. Water flow switch open. (Contact in ignitor circuit.)	Check to be sure cooling water is flowing in tubes. Determine if cooling-water temperature is below 40°C. With power removed, use ohmmeter to determine if flow switch is normally closed.
	d. Starting contact or relay fails to close ignitor circuit.	Determine if relay operates when starting switch is closed. Clean switch and relay contacts. With power removed and ignitor switch disconnected, place ohmmeter across initiating circuit and note if resistance is infinite when starting switch is open, and zero when switch is closed.
	e. Ignitron tubes have bad ignitors.	Disconnect ignitors and measure resistance (10-150 ohms).
	f. Defective copper oxide rectifier.	Disconnect rectifier from circuit and measure resistance in each direction (one approximately four times other).
	g. Defective ignitron tubes.	Replace with tubes that are known to be in good operating condition
	h. Improper connections.	Be sure tubes are mounted properly and that the anodes are connected to the correct stud or bus. Wire-check all other connections.
2. Only one ignitron passes current ("fires") when control is operated.	*a.* Bad tube.	Check 1-*e* and 1-*g*.
	b. Defective copper oxide rectifier.	Check 1-*f*.

TABLE IX.—SERVICE CHART FOR IGNITRON CONTACTORS (*Continued*)

Trouble	Cause	Test
	c. Insufficient load current.	Measure primary load current. If less than 40 amp, add sufficient load resistance in parallel with welding transformer primary to increase load current to a value above 40 amp.
3. Ignitrons fire but welding machine does not weld.	*a.* Welding transformer has an open secondary circuit.	Check all secondary connections for insulated joint. Be sure electrode holder or tips have not been shimmed with paper or some other insulating material.
	b. Welding transformer has shorted secondary circuit.	Check all secondary connections for grounds and shorts.
4. Occasional misfiring of ignitron tubes.	*a.* Dirty contacts in starting circuit.	Examine all contacts for burned, worn, or oxidized surfaces.
	b. Bad tube.	Check 1-*e* and 1-*g*. Place oscilloscope across ignitor voltage and check for consistent firing.
	c. Insufficient load current.	Check 2-*c*.
5. Ignitrons pass current as soon as line switch is closed.	*a.* Short in starting or initiating circuit.	Remove power and check for shorts with ohmmeter or bell set.
	b. Ignitron tubes gassy.	Check 1-*g* or test tube for gas with spark coil.

TABLE X.—SERVICE CHART FOR WELD TIMER

Trouble	Cause	Test
1. *CR* relay does not operate when initiating circuit is closed (see Fig. 7-26).	*a.* Faulty initiating switch does not close circuit between 5 and 6.	Remove power and check initiating circuit with ohmmeter or bell set.
	b. Faulty tubes.	If tubes have glass envelope, examine top to determine if filaments are lighted. Replace with tubes known to be good.

TABLE X.—SERVICE CHART FOR WELD TIMER (*Continued*)

Trouble	Cause	Test
	c. Capacitor 3*C* shorted.	Remove from circuit and test with ohmmeter or replace with capacitor known to be good.
	d. Capacitor 3*C* open-circuited.	Remove and measure capacity on capacity bridge or replace with capacitor known to be in good condition.
	e. 1*T* transformer secondary winding burned out.	Measure a-c voltage between 9 and 5. This should always be 115 volts a-c.
2. *CR* relay does not drop out after elapse of time delay.	*a.* Potentiometer 2*P* open-circuited.	Disconnect and place ohmmeter leads on 11 and 12, or 10 and 11. Rotate and check resistance over full range.
	b. Capacitor *C*2 shorted.	Remove from circuit and test with ohmmeter or replace with capacitor known to be good.
	c. Potentiometer 3*P* open-circuited.	Disconnect and measure resistance between 12 and 13. This is a calibration resistor and should not be rotated unless panel will be recalibrated.
3. Erratic timing.	*a.* Open grid circuit.	Check grid circuits of tubes 1 and 2 for open resistors or poor solder connections.
	b. Faulty tubes.	Check 1-*b*.
4. Short timing obtained regardless of setting of potentiometer 2*P*.	*a.* Potentiometer 1*P* open-circuited.	Disconnect and measure resistance between 10 and 5. This is a calibration resistor and should not be rotated unless panel will be recalibrated.
	b. Potentiometer 2*P* open-circuited.	Check 2-*a*.
5. Long timing is obtained regardless of setting of potentiometer 2*P*.	*a.* Potentiometer 2*P* open-circuited.	Check 2-*a*.
	b. Potentiometer 3*P* open-circuited.	Check 2-*c*.
	c. Resistor 4*R* open.	Disconnect 4*R* and measure resistance with ohmmeter.

TABLE XI.—SERVICE CHART FOR ELECTRONIC SPOT-WELDING CONTROL PANEL

Trouble	Cause	Test
1. No tubes fire when starting or initiating switch is closed.	*a.* Faulty circuit.	Check wiring of starting circuit with bell set or ohmmeter.
	b. Faulty relay (if used).	Check relay contacts. Keep all tip surfaces clean. Be sure relay operates when starting switch is closed.
	c. Faulty starting tube	Replace tube with one known to be good.
	d. Cathode protection relay not timed out	Check contact of relay. Be sure circuit closes after heating period.
2. Only starting tube operates when panel is initiated.	*a.* Faulty timing tube	Replace tube with one known to be good.
	b. Faulty component part in timing circuit.	Check timing action with cathode-ray oscilloscope. Check resistors and capacitors in timing circuit with ohmmeter and capacity bridge.
3. Only starting, timing, and trailing tubes conduct.	*a.* Faulty protective relay in firing circuit.	Check relay contacts. Be sure relay is energized.
	b. Protective relay not energized.	Be sure water is flowing in power tubes and that flow switch contact is closed. Check safety and protective switches or any devices that might directly prevent relay from operating.
	c. Blown fuses in ignitor firing circuit.	Replace fuses. Be sure ignitron power tubes are in good condition. Load current must be at least 40 amp.
	d. No timing voltage in grid circuit of firing tubes.	Check all firing tube grid voltages with cathode-ray oscilloscope. Determine if turn-on transformer is faulty.
4. Timing, trailing, and firing tubes conduct continuously.	*a.* Failure of d-c supply.	Check a-c and d-c voltages with voltmeter. Check fuses in d-c circuit. Replace rectifier tube with one known to be good. Check filter capacitors.

TABLE XI.—SERVICE CHART FOR ELECTRONIC SPOT-WELDING CONTROL PANEL (*Continued*)

Trouble	Cause	Test
	b. Faulty resistor or capacitor in timing circuit.	Check 2-*b*.
5. All tubes function except one firing tube and its corresponding ignitron.	*a*. Ignitor fuse blown.	Replace fuse.
	b. Improper setting of full heat-limit resistor.	Too much resistance shorted out of full heat-limit resistor. With cathode-ray oscilloscope, determine if 100 per cent heat occurs at some lower dial setting. Increase resistance so that full heat will occur at 100 per cent dial setting.
6. One firing tube conducts continuously.	*a*. Faulty tube.	Replace with tube known to be good.
	b. Loss of hold-off bias.	With cathode-ray oscilloscope connected from grid to cathode, determine if tube has proper hold-off grid bias.
7. Trailing tube and corresponding firing and ignitron tubes conduct continuously.	*a*. Faulty trailing tube.	Replace with known good tube.
	b. No hold-off grid bias on trailing tube.	Check hold-off bias voltage with voltmeter.
8. Erratic timing.	*a*. Faulty timing tube.	Replace with known good tube.
	b. Defective timing resistor or capacitor.	First check any variable resistors with ohmmeter. Then check other resistors and capacitors in timing circuit.
	c. Initiating circuit opening up before control has completed timing interval.	Instruct operator not to release initiating circuit until weld is completed. If cam-operated, adjust cam so as to maintain closed circuit during timing interval.
9. Loss of heat control.	*a*. Open heat-control rheostat.	Disconnect rheostat and measure resistance with an ohmmeter. Check all other resistors in series with heat control.
	b. No voltage from heat-control circuit.	Check action of heat-control voltage in grid circuit of firing tubes.

TABLE XI.—SERVICE CHART FOR ELECTRONIC SPOT-WELDING CONTROL PANEL (*Continued*)

Trouble	Cause	Test
10. Control-power fuses blow when power is applied.	*a*. Control-power transformer not connected properly.	Check primary connections to transformer. Refer to panel wiring diagram.
	b. Defective transformer in control.	Check all transformers in secondary circuit.

TABLE XII.

TYPICAL DIAL SETTING USED FOR COMPLETELY CHECKING CALIBRATION OF SEAM-WELDING CONTROLS WITH CATHODE-RAY OSCILLOSCOPE

Scope synchronized for 6-cycle pattern		Scope synchronized for 5-cycle pattern		Scope synchronized for 6-cycle pattern		Scope synchronized for 5-cycle pattern	
Weld time	Cool time	Weld time	Cool time	Weld time	Cool time	Weld time	Cool time
29	1	29	1	15	3		
1	29	1	29	3	15		
28	2	28	2			14	1
2	28	2	28			1	14
27	3	27	3			13	2
3	27	3	27			2	13
26	4	26	4			12	3
4	26	4	26			3	12
25	5			11	1		
5	25			1	11		
		24	1	10	2		
		1	24	2	10		
23	1					9	1
1	23					1	9
22	2					8	2
2	22					2	8
21	3					7	3
3	21					3	7
20	4					6	4
4	20					4	6
		19	1	5	1		
		1	19	1	5		
		18	2	4	2		
		2	18	2	4		
17	1			3	3		
1	17			2	1		
16	2			1	2		
2	16			1	1		

CHAPTER 8

INSTALLING, MAINTAINING, AND SERVICING ELECTRONIC TEMPERATURE-CONTROL SYSTEMS

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The G-E Reactrol system consists of an electronic control used in conjunction with saturable core reactors and a temperature-control instrument to regulate automatically the power input to an electrically heated furnace or process so as to maintain a preset temperature in the furnace or process.

The Reactrol system is a true input control, since there is a continuous flow of power, accurately adjusted to the immediate requirements of the electrical heating units. In this respect, this system differs from so-called "input" controls that regulate power by alternately applying full voltage and no voltage to the electrical heating units. Such input controls regulate average power input but not the instantaneous input, because when full voltage is applied to the heating units they dissipate full power.

The apparatus in a typical installation consists of five essential parts: (1) the furnace or process, the temperature of which is to be controlled; (2) one or more saturable core reactors whose a-c windings are connected in series with the electrical heating units in the furnace or process; (3) an electronic panel which controls the amount of direct current in the d-c windings of the saturable core reactors; (4) a thermocouple in the furnace or process; (5) a temperature-control instrument which is connected to the thermocouple and to the electronic control panel. Figure 8-1 is a schematic diagram in which these five parts are shown.

General Instructions

Since the electronic control equipment, temperature-control instrument, and other apparatus must be properly chosen to meet the requirements of each particular furnace or process, remarks and suggestions of only a general nature regarding installation, operation, maintenance, and servicing can be given here.

Before the installation of the apparatus is begun, instruction books, wiring diagrams, and outlines covering each piece of equipment should be obtained from the manufacturer. This information should be carefully read and understood by each person responsible for installing, operating, maintaining, and servicing the equipment.

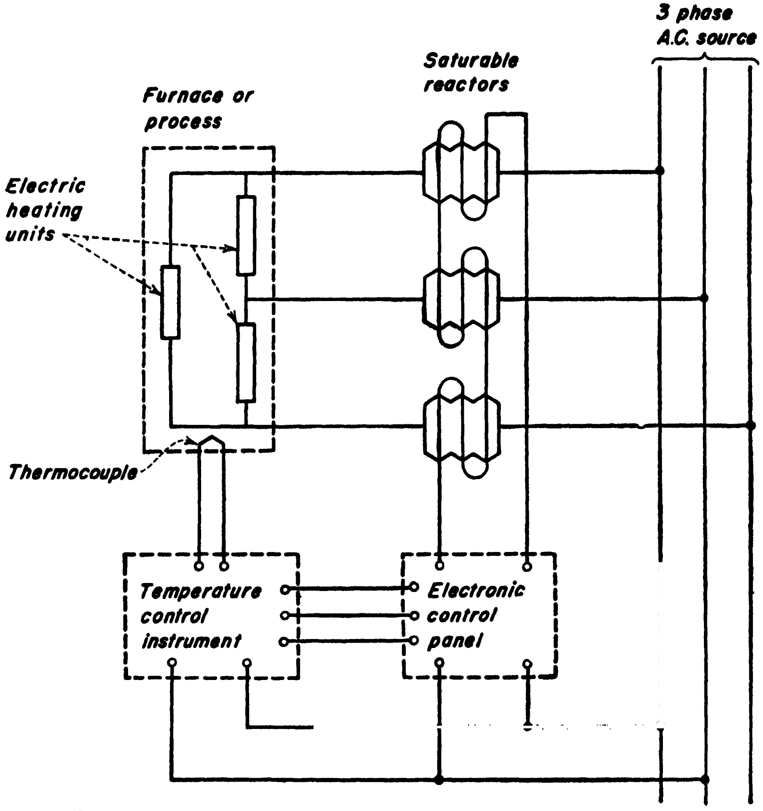


FIG. 8–1. Schematic diagram of integral parts of a typical electronic temperature-control installation.

If adequate instruction books and drawings cannot be obtained, or if essential information is lacking and qualified personnel is not available, the manufacturer should be contacted and the required assistance obtained. The reasons for this procedure obviously are to assure that the equipment is properly installed, put in service, operated, maintained, and protected from damage by inexperienced or misguided personnel.

The installation should be carefully planned so that the work will proceed with minimum confusion. The apparatus should be located with respect to the furnace in accordance with drawings, if complete installation drawings have been prepared. Otherwise, locate the apparatus so that it meets the requirements of the operating, maintenance, and service departments and complies with sound engineering principles. Figures 8-2 to 8-5 illustrate typical installations of this equipment.

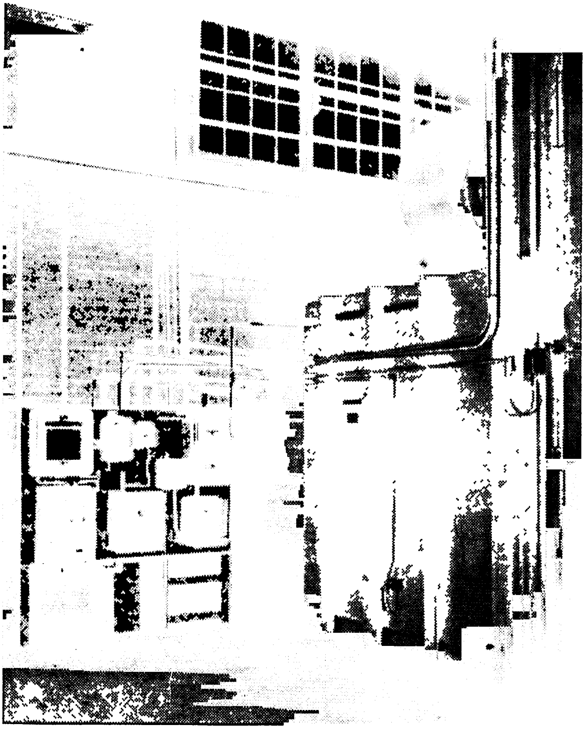


FIG. 8–2. Box-type electric furnace with air recirculation, water quench tank, and Reactrol system. Reactrol system consists of electronic control panel, temperature-control instrument, transformers, saturable reactors, and switches installed on panel at left of furnace.

The equipment should be carefully unpacked to avoid marring the enclosures or damaging the apparatus. Particular care should be exercised that no small parts are mislaid or thrown away with the packing material. If the equipment is not to be used where it is unpacked, it should be stored in a dry place and protected from accidental damage.

During shipment, the control relays and devices have their armatures or moving parts blocked or tied so as to be immovable. Remove this blocking and observe that the parts move freely and without undue friction or binding.

As a matter of precaution, do not unpack the tubes until the equipment has been completely set up and connected and power is available.

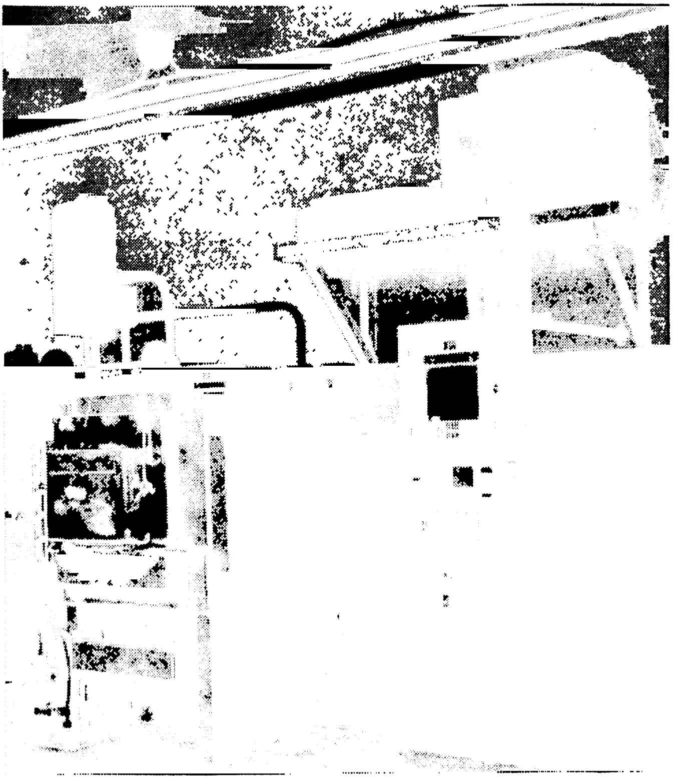


FIG. 8–3. Another box-type electric furnace used with Reactrol system consisting of panel at right of furnace with transformer and saturable reactor on shelf above panel.

Then remove them carefully from their cartons and wrappings. Save the instruction sheets that are wrapped around the thyratron and phanotron tubes, and record the installation date and serial number on that portion of the sheet which is to be used when a tube is to be returned to the factory. If a tube has been unpacked before it is to be used, repack it in its original carton for safekeeping. Avoid dropping a tube or placing it where it might fall or be accidentally knocked over. Reasonable care in handling these tubes will be amply repaid in lengthened tube life.

If a new furnace or process is to be installed, this should be done in accordance with the manufacturer's drawings and instructions. Special precautions should be taken that all safety and protective devices are properly installed.

Installation Considerations

The saturable core reactors may be mounted in any convenient location where they will be subject to free circulation of air for cooling purposes. It is important, however, that they should be located so that all power connections are short and arranged to give minimum resistive and reactive voltage drops in the power connections. The Thyrite resistor should be so located that the connections between it and the d-c windings of the saturable reactors are as short as possible.

FIG. 8-4. Reactrol system used to control a 158-kw, 440-volt, three-phase-elevator-type electric furnace having two separately controlled 79-kw heating zones. Shown are the two Reactrol panels with auxiliary control panel in between on which is mounted time clock and temperature-limiting instrument. Rack in rear carries switches, reactors, and transformers.

The electronic control panel and temperature-control instrument may be located in any convenient place, provided

1. It is reasonably free from dirt and grease and entirely free from corrosive gases or vapors—unless, of course, adequate enclosures have been included for protecting the apparatus.

2. It is free from vibration. This is especially important with regard to the temperature-control instrument because erratic operation will result if it is subjected to vibration.

3. It allows the temperature-control instrument and electronic control panel to be close together and at a convenient height for ease in operation and servicing.

4. It supplies adequate clearance for a person to work around the equipment.

Power-supply Voltage

The power-supply voltage and frequency should agree with the name-plate rating of the panel, control transformers, etc. If certain devices are to be energized from control transformers that are connected to the power supply, check the name-plate rating of these transformers to be sure that the secondary voltages are correct. These points should be carefully checked. It is also important that the power supply should be capable of maintaining rated voltage to within ±5 per cent.

Ratings of Saturable Reactors and Anode Transformer

The name-plate rating of the saturable reactor or reactors should be checked. A saturable reactor really has two ratings: that of the a-c winding and that of the d-c winding. The a-c rating includes the frequency, a-c voltage, and kva ratings. The frequency ratings should correspond to the power-supply frequency. The a-c voltage rating corresponds to the maximum a-c voltage that can be impressed across the a-c winding. On single-phase, this is equal to the a-c line voltage connected in series with the load and saturable reactor. On three-phase, when three saturable reactors and loads are connected as shown in Fig. 8-1, the a-c voltage rating should correspond to the a-c line-to-line voltage divided by 1.73.

For unity power-factor loads it is common practice to specify the total kva rating of saturable reactors as being equal to the total kilowatts of their associated load. Hence a 75-kw, single-phase load uses a 75-kva, single-phasesa turable reactor. A 75-kw, balanced, three-phase load, however, uses three 25-kva, saturable core reactors.

Because of the fact that saturable core reactors have some impedance even when carrying full saturating direct current, the maximum voltage available for the load resistor is 93 per cent of the line voltage applied to the saturable reactors and their series loads. Hence the load resistor (often called "heating unit") is designed for full kilowatt rating at 93 per cent of line volts.

The maximum alternating current for which the saturable reactor has been designed can be determined by dividing the kva rating by 93 per cent of the a-c voltage rating; and multiplying by 1,000.

The minimum possible alternating current through a saturable reactor occurs when no direct current flows through its d-c coil. The actual value of the minimum alternating current is primarily determined by the design of the reactors. For use with heating loads, two designs have been standardized. One design has a minimum current of 23 per cent of normal rated current and is referred to as a 5 per cent minimum power design, since the 22 per cent current flowing through the load resistor will dissipate 5 per cent of normal rated kilowatts in the load resistor. In similar manner, the second design has a minimum current of 10 per cent and is referred to as 1 per cent minimum power reactor.

FIG. 8-5. Reactrol system for a roller-hearth electric furnace having three heating zones. The panel at right of reactrol panels mount temperature-limiting instruments and push-buttons for operating furnace door.

The direct current in the d-c windings of the saturable core reactors is obtained by the rectifying action of the thyratron and phanotron tubes converting the a-c anode voltage into a d-c voltage. The a-c anode voltage comes from either an anode transformer or the a-c lines.

The d-c rating usually includes the d-c voltage rating and the d-c current rating. The d-c ratings correspond to full saturation of the d-c winding. They give information from which the required value of anode voltage and size of the anode transformer can be determined.

The required anode voltage is given by the following:

$$\text{Anode voltage (RMS)} = \frac{\text{total d-c voltage} + 20}{0.45}$$

The total d-c voltage is the name-plate rating for a single reactor on single phase. If two or more reactors are used with d-c windings in series, the total d-c voltage required is the sum of the d-c voltage ratings of these windings.

If an insulating-type anode transformer is used, its size should be equal to or greater than the kva calculated from the following:

$$\text{Kva} = \frac{1.25 \times 0.707 \times \text{d-c current} \times \text{anode voltage (RMS)}}{1{,}000}$$

The value of the direct current is given on the name plate of the saturable core reactor.

If the anode transformer is of the auto type, its size can be smaller and will depend upon input and output voltages and the kva calculated above.

As an example of the use of the above relations in determining the a-c rating of a saturable reactor and the rating of an anode transformer, consider the system shown in Fig. 8-6. Assume that the line voltage is 460 volts, 60 cycles. Also, assume that the name plate of the saturable reactor contains the following:

A-c winding: 75 kva, 460 volts, 60 cycles.

D-c winding: 83 volts d-c, 3.5 amp, d-c.

The calculations would be as follows:

$$\text{Max. a-c load current} = \frac{75 \times 1{,}000}{0.93 \times 460} = 175 \text{ amp}$$

$$\text{Anode voltage (RMS)} = \frac{83 + 20}{0.45} = 230 \text{ volts}$$

$$\text{Anode transf. kva} = \frac{1.25 \times 0.707 \times 3.5 \times 230}{1{,}000} = 0.712 \text{ kva min.}$$

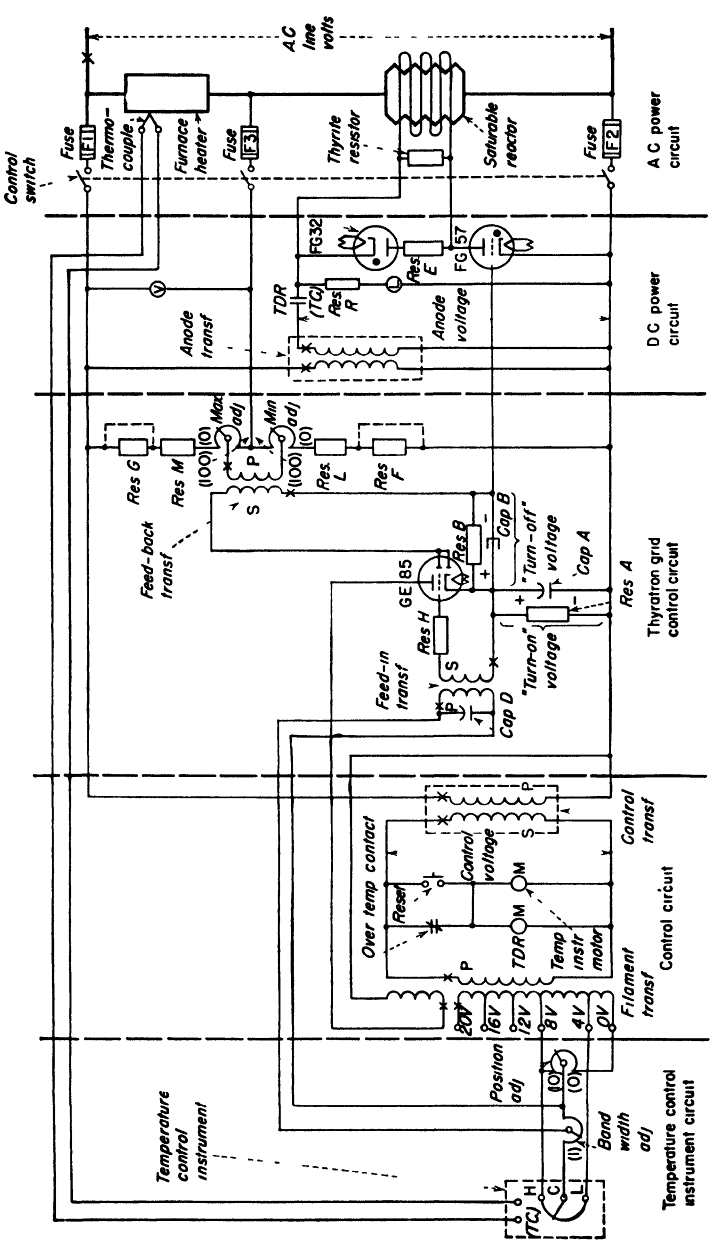
The actual rating of the anode transformer would probably be 0.75 kva, which is a standard size transformer. The complete rating of the anode transformer would be as follows: 0.75 kva, 60 cycles, 460 volts primary, 230 volts secondary.

Connections

All power and control connections should be made according to the interconnection wiring diagram. Special precautions should be taken to

1. Maintain phase relationships shown on wiring diagram and also to observe the polarities of all transformers as indicated.

2. Make power connections so that resistive and reactive voltage drops in them will be a minimum. This requirement can be met best by locating the apparatus requiring power connections so that connections will be short, power wires of adequate size are used, and wires



Leads marked "X" have same instantaneous polarity
P = Primary, S = Secondary

FIG. 8-6. Elementary diagram of typical electronic temperature-control system.

carrying single- or three-phase power be grouped together as close as practical.

3. Locate control wiring with respect to power connections so that the mutual inductance between them will be a minimum. This means that control connections should be located apart from the power connections. Control connections should not be placed in the same conduit with power connections unless space limitations make it absolutely necessary.

NOTE: When input and/or output connecting wires are run in iron conduits, it is necessary to run the incoming and outgoing wires of a pair or group in the same conduit to avoid induced currents and heating losses in the sheath. Also avoid having currents come in through one conduit and out through another.

4. Solidly ground the electronic control panel, the cases of the saturable reactors, all conduits, and the cases of all externally mounted devices.

Suggestions regarding temperature-control instruments and associated parts are listed below:

1. These instruments are delicate and should be handled with care.
2. Locate the instrument near the electronic control panel.
3. Avoid locating the instrument where it might be subject to vibration and shock, corrosive gases and vapors, and dirt and dust.
4. Follow instructions furnished by manufacturer.
5. If possible, call in a representative from the manufacturer before starting.
6. Choose a type of controlling thermocouple and locate it in such manner as to have a quick response to temperature changes.
7. After the instrument has been installed and operating, it should be left alone except for periodic maintenance recommended by the manufacturer.
8. Overtemperature protection should be provided. This may be done in several ways:
    a. By the use of an overtemperature contact in the temperature-control instrument which opens and shuts down the equipment if the temperature exceeds the setting of the contact.
    b. By use of a separate overtemperature instrument or device.
    c. By use of an overtemperature fuse located in the furnace or process.

Putting in Service and Operation

The first and most important factor for the starting and operating of a furnace or process is that all persons responsible for the successful operation of the entire system should thoroughly understand not only the functioning of the individual parts of the system, but also, to the best of their ability, the interrelated functioning of all the parts. Often it is not easy to gain a complete and thorough understanding of an entire system. Some furnaces and most processes have features which make their operation different from any other system. The instruction books usually furnished cover the devices and parts in quite complete detail. Very seldom are instruction books available which cover every phase of the entire system, and, unfortunately, such a book cannot usually be written until an installation has been completed and in successful operation.

After the installation and connections have been completed, a thorough check of all devices and connections should be made. The following check list may be helpful:

1. Has the blocking used to hold moving parts of relays, contactors, and other devices stationary during shipment been removed, and do those parts now operate freely?
2. Have all tools, temporary material, loose wires, etc., which might interfere with operation, been removed?
3. Have all packing materials, temporary structures not actually required, and surplus materials been removed? The area in the vicinity of the installation should be cleared of debris and dirt.
4. Check all connections to see that they are secure.
5. Compare all connections made during the installation with the wiring diagram. Particular care should be given to the phasing of all transformers and phase relation of connections shown on the wiring diagrams.
6. Check the devices to see that they are connected for the voltage at which they are to operate. For example, the electronic control panel may be designed for use on several voltages, but it may be necessary to make changes in it to correspond to the voltage at which it is to operate.
7. Check the sizes of all fuses to see that they are as specified.
8. Install tubes in electronic equipment as directed in the instruction book.

The general procedure to follow when putting the equipment into operation is to apply power to the devices individually, in accordance with the directions contained in the instruction books. In this way it is possible to determine whether or not the devices are functioning correctly. Reduced power should be applied to the furnace or process for the prescribed time to allow for initial heating and baking out. During this initial period, particular care and observation will be required to detect any overheating or other improper functioning of any of the parts or devices. Safety devices, limit switches, and protective features should also be checked.

Initial Adjustments

The instruction books supplied with the electronic control panel will usually describe in detail the method of making initial adjustments of potentiometers on the panel, the precautions and preheating period required when putting the tubes in operation, and a prescribed order to follow in making adjustments on the panel after it has been put in operation.

The instruction book supplied with the temperature-control instrument will usually describe in detail the initial adjustments of the instrument, and the procedure to follow when putting it in operation.

It is usually preferable to start the equipment with the temperature-setting pointer of the temperature-control instrument set at a low temperature. After power is applied to the system, carefully watch the heating units, if possible. Also carefully watch the voltmeters or ammeters that were furnished with the equipment and watch the rise in temperature as indicated on the temperature-control instrument.

When the temperature of the furnace or process reaches the preset value, readjust the controls as required to obtain stable operation. After stable operation at the low temperature has been obtained, gradually raise the temperature by advancing the temperature setting. The temperature of the furnace or process should gradually increase and stabilize close to the new preset value.

Adjustments are usually provided on either the electronic control panel, the temperature-control instrument, or both, for adjusting the system to obtain optimum performance. When these adjustments have been properly made, the system should respond to temperature variations or load variations in the furnace or process with a minimum of overshooting or hunting consistent with sufficient liveliness or speed of response. The actual performance of the system will depend upon many factors.

Checking Standard of Performance

A convenient standard of performance for a temperature-control system is the way in which the actual temperature varies when the temperature setting of the instrument is changed suddenly. Normally the actual temperature will oscillate about the new preset temperature following the change of setting. Experience has proved that the optimum performance is obtained if the temperature oscillates with a decreasing amplitude, so that the amplitude of the second overswing is about 25 per cent of the amplitude of the first overswing (Fig. 8-7). Once this condition has been obtained, it can be concluded that the adjustments on the electronic control panel and the temperature-control instrument are properly made.

The equipment should operate for a long time with but little attention, because there are few moving parts and therefore only a few parts that will require a replacement due to mechanical wear. It is advisable however, to inspect the moving parts periodically so they can be replaced before any breakdown occurs. Lubricate mechanisms and moving parts only as called for in instruction books for the particular devices.

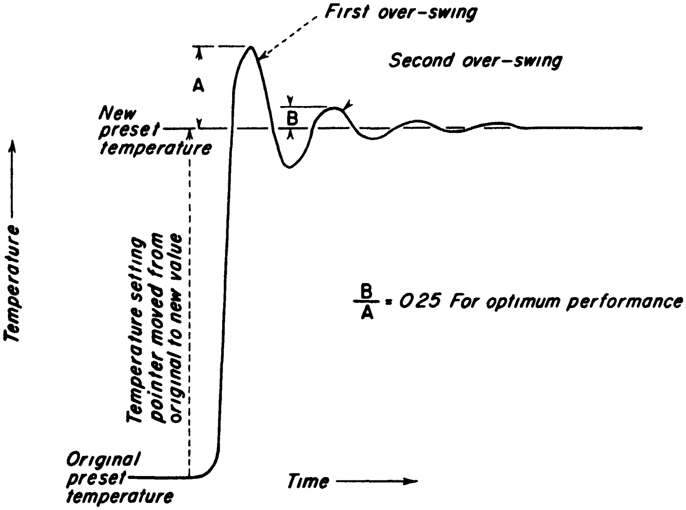


FIG. 8-7. Temperature vs. time curve resulting from a sudden change of temperature setting to adjust for optimum performance

Keep Equipment Clean

An important item in any maintenance program is that of keeping the equipment clean. Clean equipment is always easier to service than dirty equipment. A periodic cleaning may reveal conditions which, if not corrected, could result in a failure of the equipment and a shutdown.

The instruction book supplied with the temperature-control instrument will usually contain a section on maintaining the instrument. If such an instruction book is not available, it is advisable to order the required books from the manufacturer of the instrument. When ordering such books be sure to give a complete description of the instrument including information marked on its name plate, the type and model numbers, serial number, etc., to assist the manufacturer in supplying the correct books.

The maintenance of many temperature-control instruments usually includes some or all of the following:

1. Lubricating the mechanisms in accordance with instructions for the instrument.
2. Replacing recorder charts.
3. Filling recorder fountain pen with ink.
4. Renewing dry-cell batteries.
5. Cleaning the mechanisms in accordance with instructions for the instrument.
6. Inspecting contacts and slide wires to make sure contacts are clean, have adequate wipe and clearance, and pigtail connections are not worn.
7. Checking screws and nuts on mechanism and binding screws on terminal boards for tightness.

Periodic Inspection

Inspect the thermocouple or temperature-detecting means periodically to note any possible deterioration because of temperature or gas atmosphere used in the furnace or process. If a protecting tube is used for the thermocouple, examine it for flaws or deterioration. Note the condition of the special connection wires between the temperature-detecting means and the temperature-control instrument. Defective or potentially defective parts should be replaced.

Safety and protective devices such as limit switches, overload relays, and overtemperature contacts or instruments should be checked at regular intervals. Overtemperature devices can be checked by slowly raising the temperature of the furnace or process and noting the temperature at which the device operates. If the devices fail to function at their preset values, they should be repaired and put in operating condition without further delay, because their failure to operate may result in a serious damage to the equipment or injury to the personnel operating the machine.

Check all electrical connections periodically. Make sure that all binding screws on terminal boards are tight. Connections may become loose, especially if vibration is present.

Feel the cases of the transformers and saturable reactors and, if questionable, check with a thermometer to determine whether there are any abnormal increases in temperature. Signs of smoke or the odor of burning insulation around the electrical equipment may indicate overload conditions or other impending failure.

The tubes used in the electronic equipment normally will give long, continuous service. In order to maintain continuous and uninterrupted operation, it is advisable to test the tubes at least once a year. Most vacuum tubes can be tested on a radio tube tester. As facilities for testing thyratron and phanotron tubes are not so readily available, it may be necessary to make arrangements with the manufacturer for testing them. Tubes whose electron emission has fallen below normal, or which indicate that they are approaching the end of their useful life, should be replaced. Spare tubes should be kept available at all times.

Instruments for Servicing

The servicing of the equipment usually requires the use of certain test instruments. A multimeter, a vacuum-tube voltmeter, and a cathode-ray oscilloscope are the instruments best suited for servicing the electronic control panel. The method of servicing and the location of trouble in an electronic control panel can best be illustrated by considering a panel in a typical installation (Fig. 8-6). It will be seen that this system consists of five essential parts: a-c power circuit, d-c power circuit, thyratron grid-control circuit, control circuit, and temperature-control instrument circuit.

The a-c power circuit consists of the furnace heater and the a-c winding of the saturable core reactor in series with the a-c line. The d-c power circuit consists of the *FG*57 thyratron, *FG*32 phanotron, anode transformer, d-c winding of the saturable reactor, contact on time-delay relay, and, in some cases, an indicating light.

The thyratron grid-control circuit comprises the *GE*85 diode-triode tube, maximum and minimum adjustments with their associated current-limiting resistors, feedback transformer, and feedin transformer. Also included are the capacitor-resistor combinations across which appears the "turn-on" and "turn-off" voltages which are in series with the grid-cathode circuit of the *FG*57 thyratron.

The control circuit consists of a control transformer, filament transformer, time-delay relay, reset button, and overtemperature contact and temperature instrument motor actually located in the temperature-control instrument.

Before proceeding with a discussion of shooting trouble, a brief explanation of the operation of this system will be given.

It should be remembered that the primary function of the system is to regulate automatically the power input to the furnace heaters to maintain the furnace at a desired temperature. This is accomplished by means of the closed-cycle control system in which the thermocouple in the furnace develops a minute voltage which is approximately proportional to the furnace temperature. This minute voltage is in effect amplified by the mechanism or circuit in the temperature-control instrument to such an extent that an indicating pointer or pen on a chart gives a visual indication of the furnace temperature and, in addition, moves the potentiometer in the temperature-control instrument to apply the proper a-c voltage to the primary of the feedin transformer. The feedin transformer steps up this a-c voltage and impresses it on the grid-cathode circuit of the *GE*85 tube and thereby controls the "turn-on" voltage.

Locating and Correcting Trouble

Two types of trouble may be present when putting the system in operation:

1. Load voltage remains low.
2. Load voltage remains at maximum, or cannot be controlled smoothly. Methods for checking and correcting these conditions follow:

1. Load Voltage Remains Low

a. Visually inspect the tubes in their sockets to determine if the filaments are energized, which will be evidenced by a red glow at the filament and the glass bulb being hot.

(1) If the filaments are energized proceed to *c* below.
(2) If the filaments are not energized proceed to *b* below.

b. (1) Check the line voltage at the panel.
(2) Check the voltage on the primary and secondary of the control transformer.
(3) Check the voltage on the primary of the filament transformer.
(4) Measure the voltage at the filament terminals on the tube sockets. If there is rated filament voltage at the tube sockets, the tube filaments should light up, provided the tube filaments are not broken and the filament pins on the tube base make adequate connection with the tube socket.

c. Remove the *GE*85 tube.
(1) If load circuit and anode circuit for *FG*57 thyratron are intact, load voltage should increase to maximum.
(2) If load voltage does increase to maximum, trouble is in grid-control circuit for *GE*85 tube. Reinstall tube and proceed to *d* below.

(3) If load voltage does not increase, trouble is in connections. Check all connections carefully. Whether or not the anode circuit is intact can be easily checked by removing the *FG*57 from its socket and replacing it temporarily with an *FG*32 phanotron. As there is no grid in the *FG*32, it will pass full current if the anode circuit is intact. If the anode circuit is intact, install a new *FG*57 thyratron and check operation after the initial 15-min preheating period always required when installing a new thyratron or phanotron.

d. (1) Reinstall the *GE*85 tube as stated in *c*(2).

(2) Check voltage from points *H* and *L* on potentiometer in temperature-control instrument. It should be 4 volts.

(3) Check voltage across position adjustment. (This should be 8 volts.)

(4) Check voltage from points *H* and *C* on potentiometer in temperature-control instrument. It should vary from 0 to 4 volts as slider is moved on potentiometer.

(5) Put temperature-setting pointer opposite temperature-indicating pointer in the control instrument. (Instrument potentiometer slider should be approximately in middle of potentiometer.) Set band width adjustment at 1. Check voltage across primary of feedin transformer (across capacitor *D*). It should be about 6 volts with position adjustment at 0 and decrease to approximately zero, then rise to about 2 volts as position adjustment is turned from 0 to 10.

(6) Connect the vacuum-tube voltmeter or multimeter across the secondary of feedin transformer and check the a-c voltage while repeating *d*(5). Voltage should have same general shape as in *d*(5).

(7) Measure resistor *B*. It should be about 0.1 megohm.

(8) Measure d-c voltage across capacitor *A* with vacuum-tube voltmeter and repeat *d*(5). Voltage should increase from about 10 to 90 volts.

2. Load Voltage Remains at Maximum or Cannot Be Controlled Smoothly

a. Check the polarity of anode and control voltages with cathode-ray oscilloscope. These voltages should have the polarities indicated by the "X" marks on anode and control transformer on diagram.

b. Install a new *FG*57 thyratron. The 15-min preheating period for new thyratrons and phanotrons should be observed.

c. Install a new *GE*85 tube.

d. Turn minimum adjustment to 100 and maximum adjustment to 0.

(1) Check voltage across secondary winding of feedback transformer. This should be at least 70 volts a-c.

(2) Check the voltage across capacitor *B*. This should be at least 100 volts, using a vacuum-tube voltmeter.

(3) Check the polarity of anode voltage and voltage across the secondary of feedback transformer with cathode-ray oscilloscope. These voltages should have the polarities indicated by the "X" marks on anode and control transformer on diagram.

(4) Turn position adjustment to 0. Check the voltage across capacitor *A*. This should be about 10 to 15 volts d-c. Then check the voltage between grid and cathode of *FG*57. This should be about 85 volts d-c (the grid should be negative with respect to the cathode).

e. Replace socket for *FG*57 tube, as connection to grid pin may be defective.

Although the above suggestions apply specifically to the system shown in Fig. 8-6, the procedure outlined should be of assistance in servicing other types of systems.

CHAPTER 9

INSTALLING, MAINTAINING, AND SERVICING SEALED-IGNITRON RECTIFIERS

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One of the important reasons for the widespread use of sealed-ignitron rectifier units is their relative freedom from operating difficulties and consequently, their low maintenance requirements. Therefore, the reader should not become frightened by the chart of preventive maintenance items or the tabulation of how to remedy possible troubles. These troubles rarely occur; nonetheless they should be discussed so that the maintenance man can keep his sealed-ignitron unit out of difficulty and with the most reasonable expenditure of time and money.

It is the practice of manufacturers of sealed-ignitron rectifiers to furnish complete instruction books with their equipment. Also, they usually offer field engineering service during its installation. These field engineering groups help the purchaser of the equipment by instructing him how to operate it and, if it becomes necessary, by standing ready to assist in repairing it. This article is not intended to take precedence over these instructions and services. Rather, it is intended to supplement them as far as it is possible for it to do so.

Many sealed-ignitron rectifier units are operated completely unattended. Except where the equipment has been specifically sold as completely automatic, the design is usually based on the expectation that the responsibility for the operation of the equipment would be assigned to some regular operator, usually employed where the rectifier equipment is located or closely adjacent to it. However, the switchgear and control equipment furnished with sealed-ignitron rectifiers always incorporates features that fully protect the rectifier equipment, and the systems to which the rectifier may be connected, from both system faults, or failures in the rectifier equipment itself. Therefore, many users, knowing this and finding from experience that rectifier equipment invariably operates without any trouble, adopt the practice of allowing it to operate unattended.

Usually someone in the user's organization is authorized to start and stop the equipment, which in itself is a most simple operation. Sealed-ignitron rectifiers may be placed in operation by the simple expedient of closing first the a-c power circuit breaker and next the d-c circuit breaker. There are no preliminary ceremonies such as operating starting and running breakers, synchronizing, or bringing the equipment up to speed. Shutting the equipment down involves the reverse procedure. Therefore, it is not essential that those authorized to start and stop rectifiers should be technical personnel.

These authorized individuals may also be responsible for restarting the equipment in the event of unexpected service interruptions. Such interruptions are those resulting from temporary loss of a-c system voltage, short circuits on the d-c system, or arcback of the rectifier. Any of these abnormal conditions should cause the a-c and d-c power circuit breakers to open automatically. Ordinarily, service can be restored by simply reclosing the breakers.

Since unattended operation as well as starting and stopping by nontechnical personnel is allowable, there rests upon the maintenance man an unusual degree of responsibility. Not only must he be prepared to find and repair the ordinary troubles that may occur, *but he must also engage in preventive maintenance.* The latter means that, as far as possible, he must see to it that 100 per cent reliable equipment service is provided under unattended operation and normal system conditions. He should try to anticipate and correct all troubles before they occur. Experience with most electric apparatus has proved that this objective may be successfully approached by practicing carefully planned and scheduled preventive maintenance. The art of preventive maintenance for switchgear and transformers has been well known for many years. Since electronic power rectifiers are comparatively new, the need for similar planned and scheduled preventive maintenance for the rectifier part of the equipment is widely recognized. This chapter contains the well-known guides for maintaining switchgear and transformers for ready reference, in addition to suggestions prepared in the same form, but in more detail, relating to the rectifying element.

It is assumed that the sealed-ignitron rectifier is operated as a semiautomatic, unattended d-c substation.

Sealed-ignitron Rectifier Applications

Before going into the details of maintenance and servicing, some general educational material relating to sealed-ignitron rectifier units is obviously necessary. Sealed-ignitron rectifiers have been designed to supply d-c voltage to 125-, 250-, 275-, and 600-volt constant-potential utilization systems. They are also used for intermediate d-c voltages. In the most popular voltage levels—250 and 275 volts—standard ratings are available from 75 to 501 kw, and at 600 volts the ratings go as high as 1,000 kw.

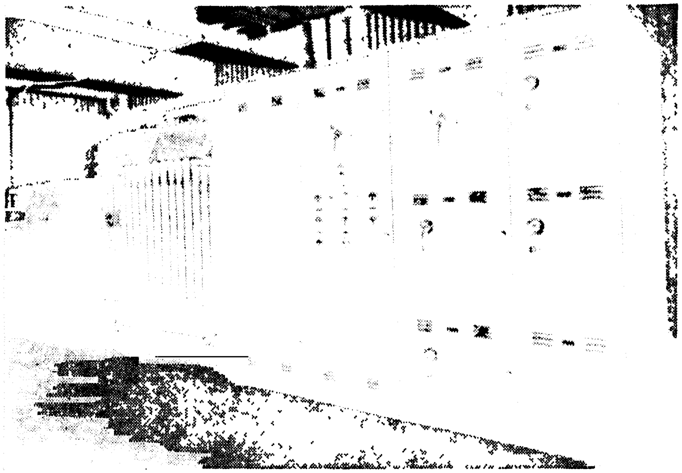


FIG. 9-1. Stationary indoor dead-front sealed-ignitron substation rated 300 kw, 250 volts, direct current for crane operation. The equipment from left to right is (1) a-c switch gear, relay and control panels; (2) rectifier transformer, Pyranol filled, and throat-connected on both a-c and d-c sides; (3) rectifier section with six 200-amp water-cooled sealed-ignitron tubes and control circuits in first panel; d-c feeder breakers and control in the other panels on right.

These rectifiers have been used for the following purposes:

- D-c cranes
- Ore bridges
- Car dumpers
- Machine tools
- Mining
- Printing
- Charging locomotives
- Railway service
- Exciters for rotating machinery
- Electrochemical processes
- Battery charging
- D-c elevators
- Hoists
- Electromagnets
- Conveyors

There are two principal forms or arrangements employed in the design of these rectifier equipments. The first, called the "stationary" type, is used for all the applications listed above. Figure 9-1 shows a typical installation of this equipment. The sky line is generally 90 to 100 in. high. All electric apparatus is metal-enclosed in dead-front cubicles. Standard switchgear, both a-c and d-c of the drawout or vertical-lift type, is employed. Transformers may be either liquid-filled (either oil or askerel), using natural ventilation, fans or water-cooling coils in the liquid, or air-cooled. The rectifier part consists of an enclosure with hinged front door or doors behind which 3, 4, 6, 8, or 12 or more water-cooled sealed-ignitron tubes are mounted, depending on the rectifier rating. In back of the tubes, and accessible through removable back plates or hinged doors, is the ignitor firing or excitation equipment. A system of piping and insulating tubing, together with various thermostats, water-pressure or flow relays, and temperature-regulating water valves, is also designed into this rectifier section for removing the heat from the sealed tubes. A d-c switchgear and rectifier control section usually contains a drawout d-c breaker, a d-c voltmeter and ammeter, d-c voltage regulator, a d-c voltage control rheostat, various protective and control relays, control power breakers or switches, and sometimes automatic panels for protecting the system in case there is regenerated d-c power—which, of course, a rectifier cannot feed back into the a-c system.

FIG. 9-2. Portable underground fully automatic sealed-ignitron d-c substation rated 300 kw, 275 volts for use in coal mine. Car at left takes incoming a-c power into automatic a-c power circuit breaker and auxiliary power transformer. Center car carries 2,300-volt, three-phase, 60-cycle, Pyranol-filled, self-cooled main rectifier transformer. Car at right (d-c car) carries six 200-amp sealed-ignitron tubes, excitation circuit, water-to-air cooler, and automatic d-c switch gear.

Figure 9-2 illustrates the second or portable form, which is used very often underground in mines. These are designed as three separate cars with wheels for drawing along the rails in the mine haulage way. Usually they are low in height—42, 48, or 60 in.—so that they can be easily moved about in mines having seams of various thickness. The three cars contain complete, fully automatic rectifier d-c substations, the a-c gear being mounted on the first car, the rectifier transformer on the second, and the rectifier, tubes, d-c gear, and water-to-air heat exchanger on the third car. These portable underground units are intended to follow the mining operations and remain as near the working face as possible in order to maintain maximum d-c voltage in the working areas.

It can readily be seen that, in effect, both the stationary and the portable forms are d-c unit substations. Either can be readily installed and moved when necessary to locations near the d-c load. Therefore it is possible for the user to reduce his power bills by locating the rectifier strategically, so that the power is brought efficiently to the load area at the high a-c distribution voltages and converted at the load center to the lower and less efficient utilization voltage. In other words, these sealed-ignitron rectifiers should be selected, applied, and used in the same manner as a-c load center stations are, since they are really d-c load center stations and offer all the well-known advantages of this type of equipment. As they are usually completely dead-front, metal-enclosed, they are safe to install in any location in a plant.

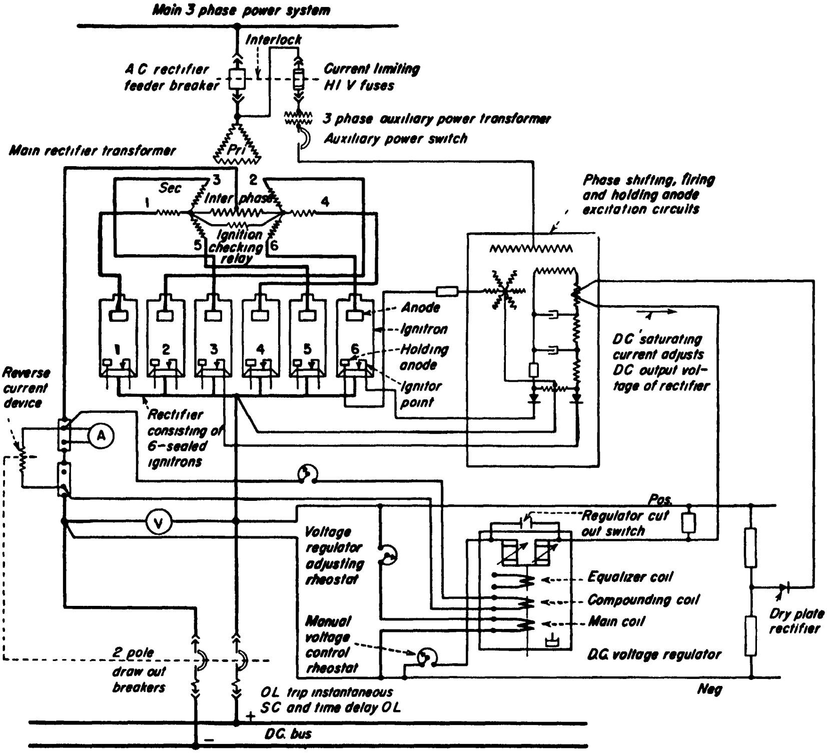

Main 3 phase power system
Interlock
A C rectifier feeder breaker
Current limiting HI V fuses
3 phase auxiliary power transformer
Auxiliary power switch
Main rectifier transformer
Pri
Sec
1
2
3
4
5
6
Inter phase
Ignition checking relay
Phase shifting, firing and holding anode excitation circuits
Anode
Ignitron
Holding anode
Ignitor point
DC saturating current adjusts DC output voltage of rectifier
Reverse current device
A
Rectifier consisting of 6-sealed ignitrons
V
Pos.
Regulator cut out switch
Voltage regulator adjusting rheostat
Equalizer coil
Compounding coil
Main coil
Manual voltage control rheostat
DC voltage regulator
Dry plate rectifier
2 pole draw out breakers
OL trip instantaneous SC and time delay OL
Neg
+
−
DC bus

FIG. 9-3. One-line diagram of a typical 250-volt sealed-ignitron rectifier.

Design of Sealed-ignitron Rectifiers

The maintenance man should know something about the design features of the equipment that he expects to service. Hence, some of these features will be described. Assuming that switchgear and transformer features are well known to the maintainer, this description will be limited principally to the main power circuit and rectifying element.

Figure 9-3 is a one-line diagram of a typical sealed-ignitron rectifier unit. It indicates all the important apparatus that is provided and how it is electrically interconnected. This diagram shows six tubes and a delta six-phase, double-wye circuit. Although such a combination will be met with most frequently by the maintainer, there are several other combinations that should be mentioned.

These different combinations have been developed to provide the different standard ratings, each with the greatest sealed-ignitron tube utility. Then there are several sizes of tubes on the market; namely, 100-, 200-, and 400- amp rating. Obviously by combining different numbers of these tubes in the rectifiers, any desired ratings may be easily obtained. Table XIII shows several standard tube and circuit combinations. There are, of course, other possibilities that are not so frequently used.

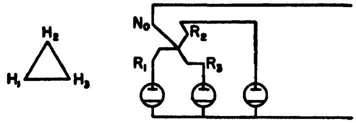
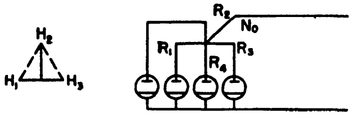
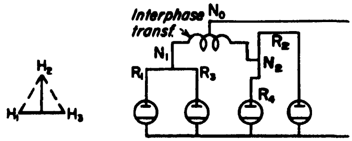
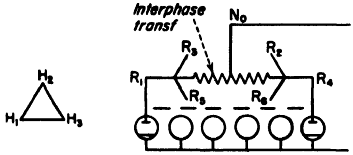
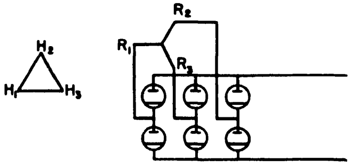
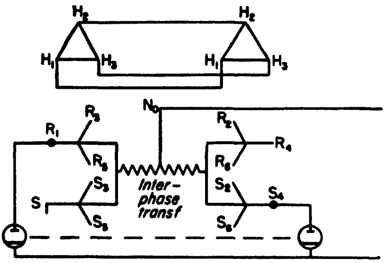
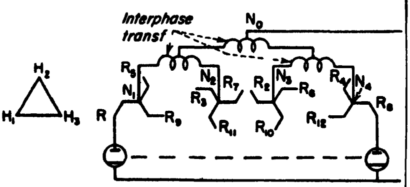
The heart of these equipments is the rectifying element, consisting of water-cooled, single-anode sealed-ignitron tubes. (Fig. 9-4). These are sealed off at the factory.

An arc is produced in these tubes each cycle and at the desired instant, just as a spark plug fires the gas in each cylinder at the right instant in an automobile engine. The spark plug or "ignitor" of the ignitron rectifier is a pencil of boron carbide slightly immersed ($\frac{3}{8}$ in.) in the mercury pool.

Stainless steel is used in the construction of sealed-ignitron tubes, so that raw cooling water, if it is fit for drinking purposes, may usually be used directly in the jackets. When insufficient raw water is available or when its purity is unacceptable, a recirculating system with a treated coolant is used. Either water-to-air or water-to-water heat exchangers are then commonly employed. Cooling water requirements for rectifiers average about 0.4 gal per min per 100 amp, d-c load.

When a system of rectifier tubes is combined as shown in Fig. 9-5 (this particular transformer circuit is chosen instead of one of those in Table XIII because it simplifies explanation), it operates to produce smooth d-c power. Figure 9-5*A* shows that the d-c output voltage follows the crest of the successive positive waves produced by the transformer secondary. A simple underlying rule for rectifier opera-

TABLE XIII.—POPULAR TUBE AND CIRCUIT COMBINATIONS

		Number of tubes
1. Delta, 3-phase, zigzag.		3
2. Scott, 4-phase, cross		4
3. Scott, 4-phase, double-diametric	 H₂ H₁ H₃ Interphase transf N₀ N₁ R₂ N₂ R₁ R₃ R₄	4
4 Delta, 6-phase, double-wye	 H₂ H₁ H₃ Interphase transf N₀ R₃ R₂ R₁ R₄ R₅ R₆	6
5. Delta, 6-phase, wye, double-way		6
6. Delta, 6-phase, parallel double-wye	 H₂ H₁ H₃ H₂ H₁ H₃ N₀ R₃ R₁ R₅ R₂ R₄ R₆ S₃ S S₅ Inter-phase transf S₂ S₄ S₆	12
7. Delta, 12-phase, quadruple zigzag	 H₂ H₁ H₃ Interphase transf N₀ R₅ N₁ N₂ R₇ R₃ R₂ N₃ R₆ R₄ N₄ R R₉ R₁₁ R₁₀ R₁₂ R₈	12

tion follows: *Provided adequate electron emission from the cathode is available and these electrons are not blocked by negative grids, only the anode or anodes most positive in the circuit will conduct current.*

Rectifier d-c output voltage can be adjusted in magnitude by adjusting the instant or time phase so that a pulse of current through the ignitor starts the arc each cycle. If the arc is delayed after the intersections of the positive half-waves as shown in Fig. 9-5*C*, the average output of the rectifier is reduced in proportion to the amount of "phase-controlled" delay.

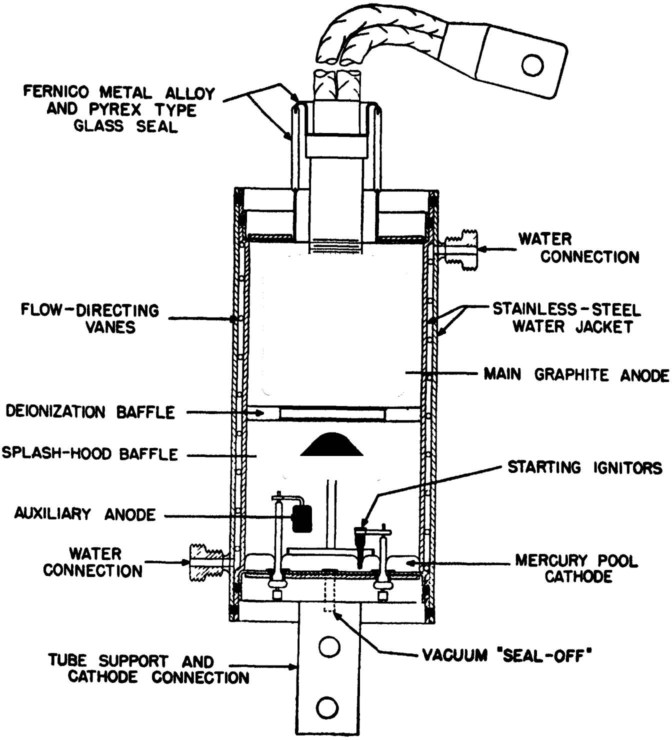
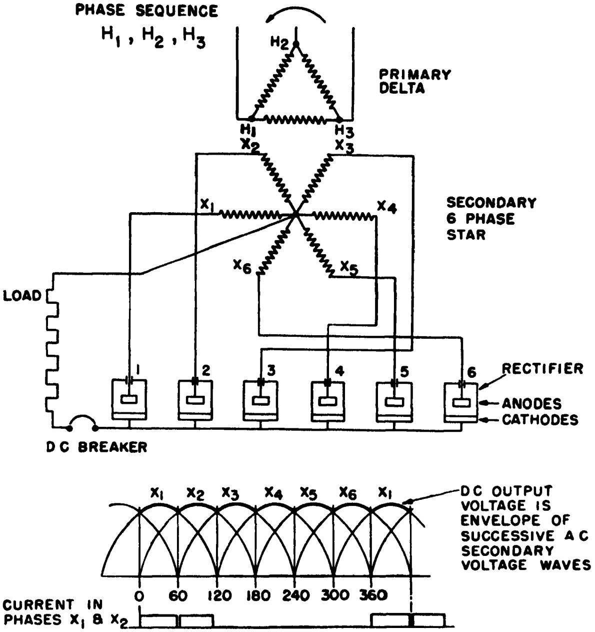


FIG. 9-4. A typical sealed-ignitron tube shown in cross section.

The ignitor firing impulses must be direct current, with the positive terminal on the ignitor, because if current flows through the ignitor in the wrong direction it will rapidly burn the ignitor tip off.

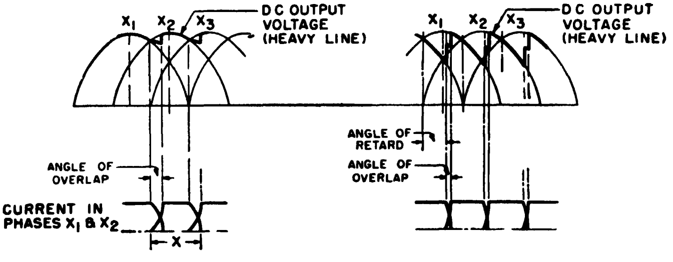
Either a-c voltage or negative voltage applied to these ignitors will destroy them.

In Fig. 9-3, "Phase Shifting, Firing, and Holding Anode Excitation Circuits" shows the type of apparatus commonly used to generate the positive impulses for firing the ignitors. The same network provides means for adjusting the time phase of these impulses and thus adjusts the main rectified d-c output voltage. Additional explanation will be given later about how these static magnetic excitation circuits function.



THEORETICAL VOLTAGE & CURRENT WAVE

(A)


X1
X2
X3
DC OUTPUT VOLTAGE (HEAVY LINE)
ANGLE OF OVERLAP
CURRENT IN PHASES X1 & X2
X
X1
X2
X3
DC OUTPUT VOLTAGE (HEAVY LINE)
ANGLE OF RETARD
ANGLE OF OVERLAP

PRACTICAL VOLTAGE AND CURRENT WAVE WITHOUT RETARDED PHASE CONTROL

(B)

PRACTICAL VOLTAGE AND CURRENT WAVE WITH RETARDED PHASE CONTROL

(C)

Fig. 9–5. Principles of mercury-arc rectifier operation and rectifier wave shapes.

Operating Characteristics

An understanding of certain rectifier operating characteristics is important to the maintenance man. Sometimes, it is only by having this knowledge that he can understand both the normal and the abnormal behavior of rectifier equipments.

In its simplest form, *i.e.*, operating unregulated, the rectifier exhibits the same voltage characteristics that ordinary power transformers or synchronous rotary converters do. That is, its output voltage mirrors the applied input voltage. Rectified output d-c voltage increases and decreases in proportion to the increases and decreases in the a-c system voltage supplying the rectifier.

D-c output voltage droops as the amount of d-c load supplied by the rectifier is increased. The amount of droop or percentage regulation depends on the amount of rectifier circuit resistance and reactance, and arc losses in the tubes. The effect of reactance on the rectifier output wave is shown in Fig. 9-5*B*. Conventional rectifiers have drooping regulation characteristics averaging between 5 and 8 per cent.

Voltage Regulation

Most sealed-ignitron rectifiers are provided with some form of d-c voltage regulator (see Fig. 9-3) which automatically regulates the amount of "phase control" and hence the d-c output voltage. Both the drooping d-c voltage characteristics and moderate fluctuations in a-c system voltage can thereby be compensated for.

Reference to Table XIII shows that circuits 3, 4, 6, and 7 have mid-tapped windings interconnecting the various secondary wye and diametric sets of windings. These are obviously balancing coils to cause more than one tube to carry current at a time, and are called "interphase" transformers. By causing tubes to share load, they improve the utility of both transformer and tubes, thereby increasing rating. However, the presence of an interphase transformer introduces a peculiarity in the d-c output-voltage characteristic that the maintainer should know about. This peculiarity is a rapid increase in the natural d-c output-voltage characteristic when the load is reduced below approximately 0.5 per cent of rated load. It is known as "light-load voltage rise" and may amount to 15 to 50 per cent of the rated d-c voltage, depending on the type of circuit. For most applications, this high light-load voltage characteristic is not objectionable since the loads never fall low enough to produce the condition. Most standard rectifiers having d-c voltage regulators compensate for this characteristic by combining a small, permanently connected d-c load on the rectifier with a wide range of phase control which is continuously and automatically adjustable by the d-c voltage regulator.

Maintainers should also remember that the power factor of the rectifier unit is adversely affected by increasing the amount of phase control.

A practical rule is that the power factor is reduced in exact proportion to the amount of phase control. If the d-c voltage is reduced 10 per cent by phase control, the power factor will be 10 per cent lower than it would otherwise be. This means that the maintainer should always try to make the rectifier transformer a-c winding (primary) tap selection, and d-c voltage-regulator adjustment, such that a minimum amount of phase control is used to hold the desired d-c voltage.

The maintenance man will also find it very helpful to study the blueprints supplied with the equipment, particularly the elementary wiring diagrams. Many maintainers commit important parts of these diagrams to memory, so that they can inspect the apparatus and locate troubles quickly without a time-consuming study of the diagrams.

Periodic Inspection

An inspection chart, for guidance, should also be one of the maintainer's tools. Table XIV is designed for that purpose. It is based on daily, monthly, and annual programs of preventive maintenance which should successfully meet the requirements for average installations. In compiling this chart it was assumed that the rectifier equipment was kept in continuous operation. Many other such factors, as well as local conditions, may influence the frequency of inspection. Obviously, when dirty or gassy atmospheric conditions exist, more frequent cleanings and inspections are imperative. The schedule will also depend upon the amount of load and degree of service reliability required. All this adds up to the fact that the maintainer is urged to exercise good judgment in applying the suggestions contained in this inspection chart, particularly as to the frequency of the inspection programs.

Preventive Maintenance for the Rectifier Components

Table XIV outlines what to inspect and what to look for, covering all components of the equipment. However, as mentioned earlier, it is assumed that the maintainer will have available from other sources all the necessary descriptive material and recommendations covering the a-c and d-c switchgear and transformers. The following text will deal specifically with the various parts of the rectifier component. It will also cover what has to be done by the maintainer when he carries out the itemized inspection work in the last column on the chart, "What to Look For."

How to Take Care of the Cooling System

There are three types of cooling systems in common use with sealed-ignitron rectifiers:

1. Direct Raw-water Cooling. The raw water is discharged to the sewer.

a. The raw water circulates through the tubes under pressure from a tap-water system, and the amount of water is controlled by either a manual throttle valve or an automatic thermostatically controlled valve (Fig. 9-6*A*).

b. Raw water is circulated through the tubes at a constant rate by an auxiliary motor-driven water pump. A mixing tank is used, and some desirable range of water temperature through the tubes is held by regulating the amount of fresh raw water entering the mixing tank. Usually the flow is controlled by means of a manual throttle valve or an automatic thermostatically controlled valve (Fig. 9-6*B*).

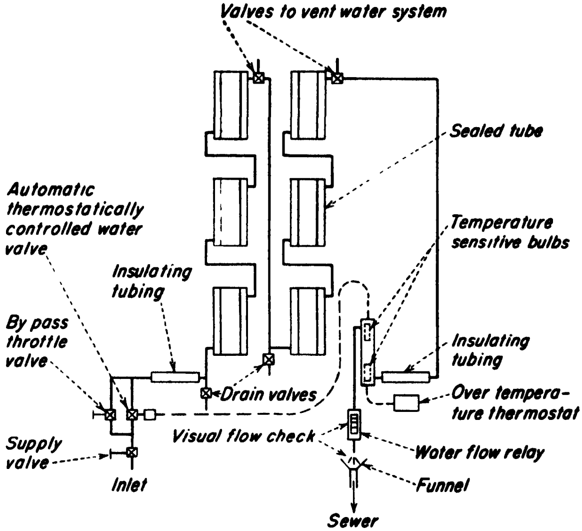


FIG. 9-6*A*. Direct raw-water cooling system used with six sealed-ignitron tubes. Water circulates through tubes under pressure of tap-water system.

2. Water-to-air Heat Exchanger. A coolant, which may or may not be treated with rust inhibitor or antifreeze, is circulated through the tubes and a surface air cooler by an auxiliary motor-driven water pump. The losses are removed from the surface air cooler by a motor-driven blower (Fig. 9-7*A*).

3. Water-to-water Heat Exchanger. A coolant, which may or may not be treated with rust inhibitor, is circulated through the tubes and a water-to-water surface cooler by an auxiliary motor-driven water pump. The losses are usually removed from the water-to-water surface cooler by passing raw water through the surface cooler under pressure from a raw-water system, and the amount of water is controlled by either a manual valve or an automatic thermostatically operated valve (Fig. 9-7*B*).

Direct raw water should be used for cooling only when its purity is suitable and can be obtained at a reasonable cost. Most water fit for drinking is suitable, but to qualify for direct use in the stainless-steel sealed-ignitron tubes it should have the following characteristics:

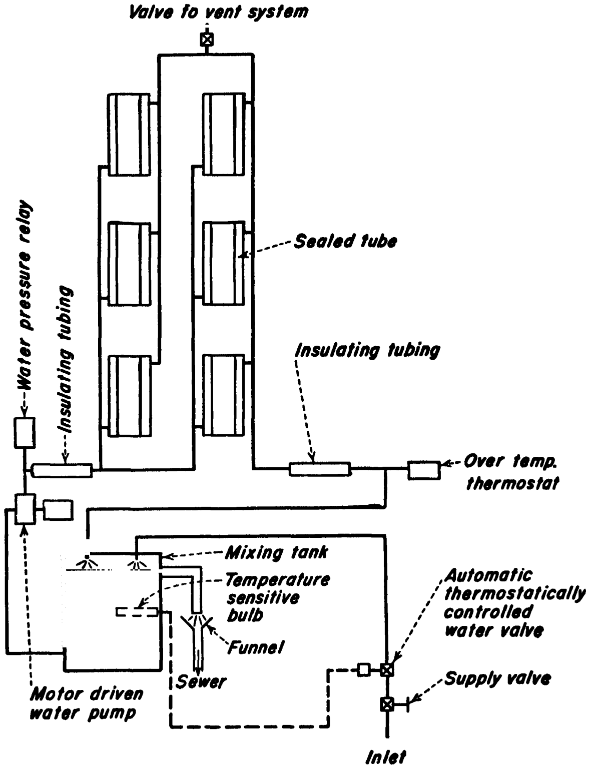


FIG. 9–6*B*. Raw-water cooling of sealed-ignitron tubes is obtained by circulating water from mixing tank through tubes at constant rate by an auxiliary motor-driven water pump.

1. Neutral or slightly alkaline reaction, *i.e.*, a pH between 7.0 and 9.0.
2. A chloride content of not more than 20 ppm; a nitrate content of not more than 10 ppm; and a sulphate content of not more than 100 ppm.
3. A total solids content of not more than 250 ppm.
4. A total hardness, as calcium carbonate, of not more than 250 ppm.
5. Minimum resistivity of 2,000 ohm-cm.

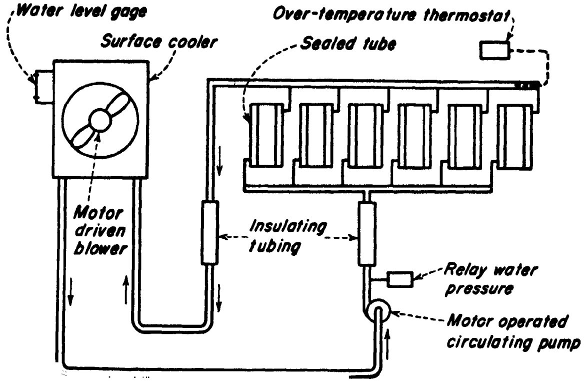


FIG. 9–7A. Water-to-air heat exchanger for cooling sealed-ignitron rectifier tubes.

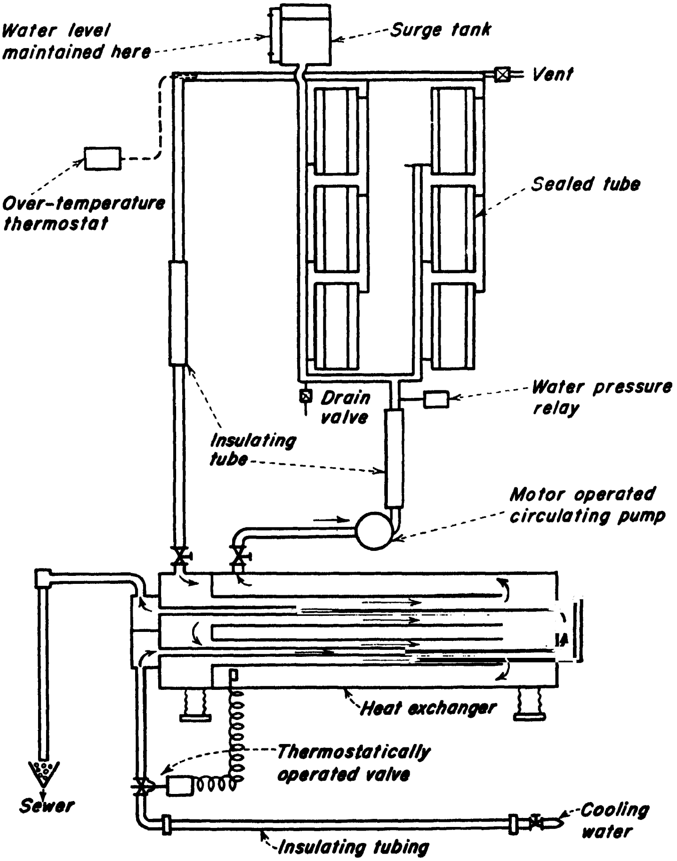


FIG. 9–7B. Water-to-water heat exchanger for cooling sealed-ignitron rectifier tubes.

Direct raw-water systems are the most popular types because they are simpler and there is usually available water that passes the above requirements. However, nearly all mining rectifiers use water-to-air systems because the mine waters are acid and corrosive.

When mixing tanks are employed, obviously the only purpose is to maintain some desirable fixed velocity of water and a fixed temperature on all the tubes. On the other hand, water-to-water heat exchangers are employed when an inexpensive and adequate supply of raw cooling water is available, but its purity is not satisfactory for direct use on the tubes.

Checking Water Flow in Direct Raw-water Systems

If direct raw-water cooling is used, it usually is discharged to the sewer after passing through the rectifier. Generally, arrangements are made at or near the point of discharge for visual inspection of the water flow. This arrangement may be an open funnel at the sewer connection into which the discharge water goes, or a sight gauge in the water piping where the water can be seen. Some rectifiers are equipped with water-flow relays which have calibrated sight gauges. Then the rate of water flow can be quickly checked (in gallons per minute) by reading this gauge. Therefore, when direct raw-water cooling is used, the quick way to make the daily water-flow inspection is to check it visually.

Raw-water cooling systems such as that shown in Fig. 9-6*A* are nearly always equipped with water-flow relays (Fig. 9-13) which should be set to trip the rectifier off in case of too little cooling water. Sometimes these relays become inoperative and fail to trip the rectifier when water fails. The cause is usually incrustation, sedimentation, or debris in the water passages of the relay. When the maintainer finds water conditions that tend to cause such clogging of the relay, he should disassemble the relay and remove this material frequently enough to prevent failure. The simplest way to test the operation of the flow relay is to cut off all water to the rectifier by momentarily closing the supply valve. This should cause the relay contacts to operate. If the rectifier is under load, it should shut down, unless the contacts are shunted out temporarily during the test.

Reference to Fig 9-6*A* will show a by-pass throttle valve around the automatic thermostatically operated water valve. This by-pass valve should be adjusted to allow the constant flow of a relatively small volume of water. The purpose of this trickle is to have some water always flowing past the sensitive bulbs of the overtemperature thermostat and the automatic water valve. Otherwise these devices would not get a signal when the tube temperatures increase, as the rectifier starts to carry load. Obviously, the water-flow relay must be adjusted to shut down the rectifier when the water flow falls lower than that volume allowed to flow constantly through the by-pass valve. The manufacturer's instructions should be followed in making the correct relay and by-pass valve settings. An occasional check on the quantity of water flow through the by-pass, measuring the discharge rate into a pail, is advisable to see that the calibration of the by-pass valve remains fixed.

Raw-water cooling systems such as that shown in Fig. 9-6*B* require checking both the raw-water supply and the recirculating water to make sure that there is adequate cooling water. Inspection of the water level in the mixing tank will indicate whether the system is full. Water should be level with the tank discharge pipe. Since for these systems there is no by-pass throttle valve and no water-flow relay, there will not always be discharge water flowing to the sewer. When there is, a visual examination instantly proves that the raw-water supply is adequate. Under no-load condition, no discharge water should be flowing, and it is necessary to wait until sufficient load is present to check the discharge water, or otherwise temporarily reset the automatic water valve down to a temperature low enough to cause it to open.

Automatic Water Valve

The automatic water valves are usually mechanical valves (Fig. 9-8). The poppet of the valve is operated by a rod connected to a diaphragm or sylphon bellows. These bellows are in turn connected by a capillary tube to a sensitive bulb and the latter system partly filled with a liquid whose boiling point is near the temperature that it is desirable to maintain. Its vapor pressure thus corresponds to the temperature of the liquid in the sensitive bulb (the bulb being in the rectifier cooling water) and consequently the position of the diaphragm or bellows depends on the vapor pressure. Vapor pressure in the sylphon is balanced by an adjustable bellows return spring. Thus the position of the valve poppet will depend on the sensitive bulb temperature. The operating temperature of the valve is adjustable by setting the bellows return spring pressure. For most sealed rectifiers this setting should be such that the valve opens at 30 to 35°C.

Operation of the valve may be tested while the rectifier is under load. Mark a point on the operating rod of the valve. Then restrict the supply water to the rectifier temporarily to a volume less than that needed to hold the temperature constant. The automatic valve should open wide when the temperature increases above its setting and the marked operating rod should move in the direction away from the bellows. Then suddenly open the supply-water valve and the rush of raw water should cool the rectifier down quickly below the setting of the automatic valve, when the valve should close completely. Differential between completely open and completely closed should not exceed 5°C.

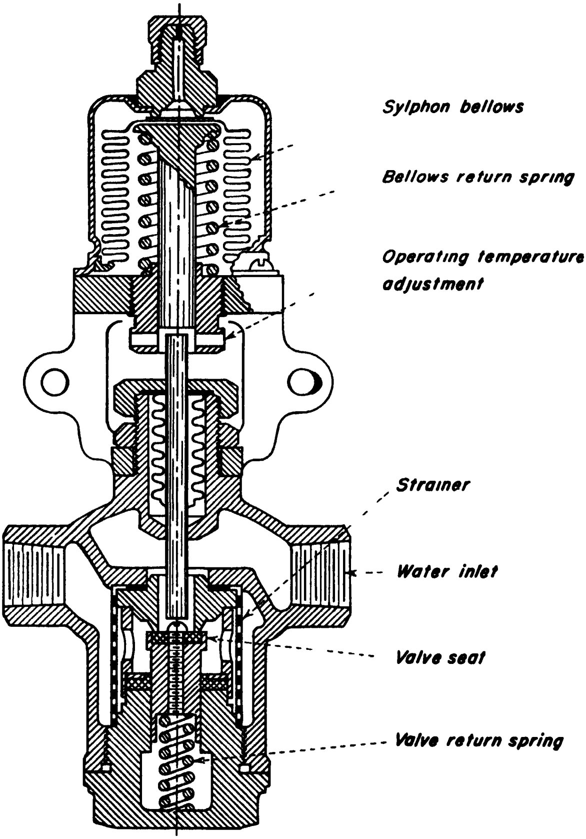


FIG. 9-8. Cross-sectional view showing internal parts of a typical automatic water valve

Sometimes these water valves become clogged with sediment or debris. This causes the valve to be sticky in action and may prevent complete closure. If the valve is sticky, it will be noticed that the differential between open and closed position will exceed 5°C; therefore, the operating temperature of the rectifier will fluctuate abnormally over a wider range. When this occurs (and the maintenance man will soon find, from experience, how often to expect it), the bottom cap should be removed and the strainer and inside of the valve carefully cleaned. It may even be advisable to replace the valve seat, if it is replaceable, or to reseat the poppet with pumice powder, if the seat is not replaceable. Care should be exercised in reassembly, so that all parts are mechanically free and properly aligned. The operating rod enters the valve body through a stuffing box. This box must not be tightened too much, as it will increase the friction loading on the bellows and make the valve sluggish.

Checking Water Flow in Recirculating Systems

Water-to-air and water-to-water systems make use of recirculation. This means that there must be a tank, reservoir, or surface cooler in which a minimum level of coolant must be held. Usually these devices are equipped with glass water-level gauges in which the desirable level is marked. Regular daily inspection should always include checking these gauges and, when necessary, filling the system with more coolant. If the coolant contains antifreeze, it may evaporate more rapidly and the system will require more frequent refilling. When the sight glass becomes dirty or stained, it should be removed and the inside of the glass cleaned.

A centrifugal pump is used to circulate the coolant. As it is installed at a level in the system below the minimum water level, it always remains primed. The pump is ordinarily immersed in the coolant with a vertical motor drive to avoid the need for a packing gland and attendant leakage. If the pump has packing glands, they should be kept reasonably tight and the packing changed regularly to avoid excess leakage. Vertical pumps that have the pump below water and the motor above, require only annual lubrication. It is most important to avoid excess grease. Occasionally the pump should be inspected for loose nuts and connections. If vibration occurs, the pump should be disassembled and any worn or unbalanced parts replaced. Before restarting be sure that the shaft is properly aligned by turning it over by hand. There should be no binding.

Recirculating systems employ electrical water-pressure relays to protect the rectifier in case of loss of water or motor-driven pump failure. These relays are set to operate just below the normal water pressure at the discharge of the circulating pump. The relays may be tested by stopping the motor-driven pump, which should cause the rectifier to shut down unless the relay contacts are temporarily shunted. It is advisable to test the relay calibration by means of a pressure gauge at least annually.

Corrosion Prevention

There are two kinds of corrosion which may be experienced in connection with sealed-ignition rectifiers—atmospheric and electrolytic.

Atmospheric corrosion is always at work, particularly where iron or ferrous parts are used in the cooling system. It is caused by the oxygen dissolved in the coolant. Electrolytic corrosion is met only when a difference of potential exists between various parts of the cooling system. Atmospheric corrosion may be satisfactorily controlled by using corrosion-resistant materials in direct raw-water systems or by using corrosion inhibitors in recirculating systems. Electrolytic corrosion is controlled by eliminating differences in potential in the cooling system or by minimizing the electrical leakage current between parts at different potential and using electrolytic targets.

Corrosion Inhibitors

When no difference of potential exists, there are two corrosion inhibitors which may be added to the liquid that is used in the recirculating part of a rectifier cooling system and which experience indicates are effective and safe. The most effective and widely used inhibitor is sodium chromate (Na_2CrO_4). In making up the solution, it is preferable to use pure distilled water, in which case add one-tenth of 1 per cent by weight of anhydrous sodium chromate to the distilled water. If distilled water is unavailable, water of the characteristics previously given for direct raw-water-cooled rectifiers may be employed. In this case, add one-half of 1 per cent by weight of anhydrous sodium chromate.

As will be discussed in a later section, sodium chromate reacts unfavorably with ethylene glycol antifreezes. When this antifreeze is used, Borax ($Na_2B_4O_7 \cdot 10H_2O$) must be employed. This is in general not as effective a corrosion inhibitor as sodium chromate, and therefore sodium chromate should be used whenever it is permissible.

Testing the Strength of Sodium Chromate Solution

Usually systems making use of sodium chromate or sodium dichromate as an inhibitor in the coolant do not require cleaning if the corrosion inhibitor is kept at proper strength. The strength of the corrosion inhibitor in a coolant may be tested as follows:

1. Equipment used:
   - *a.* 6-oz wide-mouth glass bottle.
   - *b.* A cork or rubber stopper provided with two polished iron-wire electrodes protruding through the stopper and extending to within ½ in. of the bottom of the bottle. The electrodes should be iron wire $\frac{1}{16}$ in. in diameter and spaced 1 in. apart.
   - *c.* A d-c source of power 5 volts potential from dry cells or storage batteries.

2. Tests:

Fill the bottle with a sample of the coolant in question. Maintain some convenient temperature, always using the same temperature for each of the tests, to get comparable results. For instance, use the average ambient temperature for the locality. Insert the stopper with the electrode and apply 5 volts across it. If the solution is too weak, a grayish cloud formation of precipitate will become visible near the iron electrodes within 5 to 30 min. After several minutes the gray precipitate changes to brown or iron oxide.

When evidence of weak solution is found, the solution should be strengthened and a test repeated. When the solution is of proper strength, it will remain clear throughout the test. For each test the bottle should be cleaned thoroughly and the electrodes should be cleaned, or replaced if necessary. In replacing the electrodes, proper spacing should be maintained.

Control of Electrolytic Corrosion

Sealed-ignitron rectifier equipments may be arranged in several different ways to meet the problems arising from electrolytic corrosion caused by difference of potential between various parts of the water cooling system:

1. **Single-way Rectifier, Grounded Negative.** The ignitron tubes in single-way rectifiers operate at the same potential as the positive terminal of the rectifier, and therefore in this case they are at a different potential from ground. When either direct raw water or a water-to-water heat exchanger using direct raw water is used for cooling, it is obvious that a difference of potential will exist across the cooling system between the tubes and the grounded part of the user's raw-water system.

In a direct raw-water cooling system the leakage currents between the tubes and ground, which create electrolytic corrosion at the anodic (positive) points in the water piping system, are kept below maximum allowable values by the use of insulating hose or tubing. Thus, the incoming cooling water and outgoing cooling water are carried between the grounded system and the tubes through a sufficient length of hose to increase the electrical resistance of the two columns of water to a value high enough to reduce the electrolytic current satisfactorily.

When a water-to-water heat exchanger is used, it is preferable to insulate the heat exchanger from ground so that it can be operated at the same potential as the rectifier tubes. The direct raw water is carried back and forth between the user's raw-water system and the heat exchanger through insulating hose or tubing, and electrolytic corrosion is controlled by using a sufficient length of water column as described in the preceding paragraph. Since the heat exchanger is at the same potential as the tubes, sodium chromate may be used as an inhibitor in the recirculating coolant.

When a water-to-air heat exchanger is used, it is desirable to insulate the heat exchanger and operate it at the same potential as the rectifier tubes. In this case a corrosion inhibitor may also be used.

Although it is undesirable, rectifiers are sometimes built with grounded water-to-water or water-to-air heat exchangers. In these cases sufficient insulating hose or tubing to control the electrolytic current below the maximum allowable value must be used between the heat exchanger and rectifier tubes. No corrosion inhibitors should be used under these conditions, and particular attention must be given to maintaining high resistivity of the coolant. Since the coolant is reused in recirculating systems, impurities tend to concentrate in the coolant, and so the coolant should be replaced every few months.

Serious corrosion and early damage to the cooling system of rectifier units having both grounded negative and grounded heat exchangers are avoided only at the price of constant vigilance by the maintenance man. The most effective preventive maintenance procedure in this case is regular testing of the resistivity of the recirculating coolant. The use of distilled water (200,000 ohm-cm) is recommended for both initial filling and make-up. Whenever the coolant falls as low as 5,000 ohm-cm, it should be replaced. Ohm-centimeter is a term meaning specific resistance in ohms between two opposite faces of a centimeter cube of the coolant. Apparatus for measuring quickly the coolant resistivity can be purchased from the rectifier manufacturer.

2. **Single-way Rectifier, Ungrounded D-c System.** The same rules apply as for (1), since accidental and leakage grounds must always be assumed. Experience shows that it is conservative to assume that ground exists at a point approximately midway between the positive and negative sides of the d-c system.

3. **Double-way Rectifiers.** All the tubes in a double-way rectifier do not operate at the same potential (refer to Table XIII, circuit 5). Therefore it is necessary to control the leakage current between tubes by using a sufficient length of hose to give the needed resistance in the water column. The control of electrolytic corrosion for the other parts of the rectifier cooling system is based on the same rules as given under (1), (2), and (3).

4. **Electrolytic Targets.** The effect of electrolytic corrosion on the piping at anodic points can be minimized by the use of electrolytic rods or targets. These devices, which can be constructed of copper, iron, lead, platinum, or other metals, depending upon the chemicals in the

cooling water, are pipe fittings which may be easily removed and replaced when they are worn out by the concentrated corrosion at their surface. They are inserted in the positive water piping at the points in the system next to the insulating hose or tubing in such a way that the rod extends well into the insulated part of the system. Thus they act as targets for the collection of the leakage current and save from damage other metal parts of the water system which are more expensive and difficult to replace. When properly designed, they will collect more than 99 per cent of the leakage current and are extremely effective.

Copper electrolytic rods should never be used where any sodium chromate is present in the water flowing over the target. When sodium chromate is present, iron targets may be used if electrolysis is mild. When distilled water is the coolant, stainless steel, copper, or solder targets are used. If it is desirable to reduce the frequency of electrolytic target replacement, the rod may be constructed with platinum sheaths exposed as target area. Platinum is affected very little when exposed to electrolytic current at anodic points in an electrolytic system.

When the rectifier is equipped with electrolytic rods or targets, the maintenance man should examine them frequently enough at first so that he can set up a schedule for target replacement which will prevent damage to the rest of the system, should it be operated with targets that have been completely corroded away.

Antifreezes

It is often necessary to use an antifreeze in the recirculating coolant of sealed-ignitron rectifiers. Usually when it is necessary thus to prevent freezing of the coolant, the sealed-ignitron rectifier is also supplied with a water-to-air heat exchanger.

Experience has proved that methyl alcohol base antifreezes are the best. Methyl alcohol and pure water is the only solution that should ever be used in systems where a difference of potential exists. In systems where no potential difference exists, 0.1 per cent sodium chromate and 1 per cent borax by weight should be added to the methyl alcohol and pure water solution to act as a corrosion inhibitor.

Ethylene glycol should be used only where no difference of potential exists. It should be used with pure water, and 1 per cent borax by weight should be added to keep the solution alkaline and reduce corrosion. Presence of even traces of sodium chromate in the coolant react adversely with ethylene glycol. Ethylene glycol solutions tend to turn acid, and they should not be used longer than one season.

Some commercial antifreezes contain the ingredients specified above; and when it can be definitely established that they conform, it is safe to use them. However, as commercial products are subject to change without notice, it is believed that the safest procedure is for the maintenance man to make up the antifreeze solutions required, using only commercially pure ingredients, all of which are easily obtained.

There are a few precautions to be observed in connection with alcohol-base antifreezes. These are inflammable, particularly when handled in their concentrated or pure form. Also, loss of alcohol by evaporation should be minimized to reduce the operating expense. This evaporation can be reduced by operating the coolant at as low a temperature as possible, keeping within the manufacturer's recommended operating range, and by keeping the system well closed. This means that all openings to atmosphere should be eliminated except those required to permit successful breathing.

General Rules for Use of Corrosion Inhibitors and Antifreeze

The foregoing comments and rules, pertaining to the use of corrosion inhibitors and antifreeze in various types of rectifier cooling arrangements, have been condensed for handy reference. These rules are given below:

Coolant Schedule
for
Mercury-arc Rectifiers Having Heat Exchangers

No Voltage across Piping. (Heat exchanger insulated from ground.)

Antifreeze never required:

All year pure water[1] and 0.1 per cent[2] sodium chromate.[3]

Antifreeze required:

Summer: Pure water, 0.1 per cent sodium chromate, and 1.0 per cent borax (best recommendation).[4] Pure water and 1.0 per cent borax (alternative recommendation).

Winter: Pure water, methyl alcohol, 0.1 per cent sodium chromate, and 1.0 per cent borax. Add water only in spring; replace solution in fall when antifreeze is put in (best recommendation). Pure water, ethylene glycol, and 1.0 per cent borax. Discard this solution each spring (alternative recommendation).

Voltage across Piping. (Negative d-c and heat exchanger both grounded).

Antifreeze never required:

All year: Pure water, replace when resistivity falls to 5,000 ohm-cm.

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[1] Pure water is water having a minimum resistivity of 30,000 ohm-cm.

[2] For systems with 30 gal. capacity, 1.0 per cent is 2½ lb. and 0.1 per cent is 4 oz.

[3] Anhydrous sodium chromate (Na_2CrO_4) must be used to obtain correct proportions.

[4] Borax ($Na_2B_4O_7 \cdot 10H_2O$) may be 20 Mule Team brand or equivalent.

Antifreeze required:
Summer: Pure water, replace when resistivity falls to 5,000 ohm-cm.
Winter: Pure water and methyl alcohol; replace when resistivity falls to 5,000 ohm-cm.

Methods of Cleaning Cooling Systems

Water-to water heat exchangers are always designed so that the raw-water side of the heat exchanger may be readily cleaned of any accumulation or sedimentation. The maintenance man should find from experience how often to clean the raw-water side of these water-to-water heat exchangers for each particular location.

If inspection shows that the passages of the recirculating cooling system, which are not accessible for direct mechanical cleaning, have become clogged and cooling efficiency has been reduced, a more complete cleaning of the system is indicated.

The use of chemicals for cleaning purposes is generally undesirable, especially if corrosion has been severe. If the chemical cleaner is effective, the base material remaining after severe corrosion may be so weak that leaks may develop and fittings may have to be replaced. For this reason, disassembly of the piping system and replacement of badly corroded parts may be the better procedure. If this is done, those parts which are not replaced can be scraped clean of corrosion before reassembly of the piping. Severe corrosion is not generally encountered in rectifier cooling systems. If it is, other steps in addition to cleaning should be taken to overcome the cause of the corrosion.

Parts of the system which cannot be disassembled, such as the heat exchanger, can often be adequately cleaned by flushing with water under high pressure. Admitting compressed air to the water is often employed as a means of increasing turbulence in the water. This same idea can also be applied to cleaning a complete recirculating system if corrosion has not been excessively great.

Chemical cleaning should not be undertaken unless large quantities of pure water are available for flushing, as all traces of the cleaning compounds must be rinsed from the system.

Whenever chemical cleaning becomes necessary, the following procedure is suggested:

A solution of 5 per cent by weight sodium bisulfate ($NaHSO_4$) and 2½ per cent by weight of oxalic acid $(COOH)_2$ should be made up and introduced into the cooling system. To this cleaning solution should be added 0.012 per cent by weight of Rodine No. 67 inhibitor to reduce the tendency of this solution to dissolve base metal without reducing its ability to attach rust and scale. The solution should be heated to a temperature of 50 to 60°C and circulated by means of the water circulating pump for a period of 8 hours or more. The solution can often be heated to the desired temperature by energizing immersion heaters which are connected to the control circuits and are mounted in the surge tank.

The length of cleaning time necessary can be determined by inspecting the inside of parts of the piping which are accessible, such as the interior of the surge tank, and noting the degree of cleaning which has taken place.

At the end of the cleaning period the cleaning solution should be drained and the system rinsed once with pure water. After this the system should be filled with a solution containing 1 to 2 per cent by weight of washing soda (sodium carbonate—Na_2CO_3), which acts to neutralize the acids used for cleaning. This neutralizer should be circulated for approximately half an hour at normal temperature. It should then be drained and the system flushed three or four times with pure water before filling it with the final operating cooling solution.

If evidence of unusually bad corrosion, or heavy scale deposits are found, it is advisable to emphasize the condition to the manufacturer's representative and get his recommendations for overcoming the trouble.

How to Care for the Tubes

Strictly speaking, there is not much that can be done in the way of preventive maintenance for sealed-ignitron tubes. There are, however, certain records that should be kept and certain matters that should be well understood in connection with the handling of these tubes.

Tube Record Book

It is advisable for the maintenance man to keep a tube record book. Most sealed ignitrons have a life warranty. A typical warranty is the so-called "36-48 month life warranty." The 36-48 monthly warranty means that the tube is guaranteed for 36 months' operating service and, in addition, 12 months of shelf life. The latter provision is obviously to protect the user adequately for those tubes which he maintains as spares.

The purpose of keeping a tube record book is to record the performance of the tubes in sufficient detail so that the user can tell whether or not he is obtaining the expected tube life. Then, if it is less than what should be expected, the record book will show this and the maintenance man can look for the cause of the unsatisfactory performance or call in the manufacturer's field representative for recommendations. Under such conditions, the record book helps the manufacturer's field engineers in analyzing the performance of the rectifier with the object of improving performance.

Arcback

Most rectifier users keep an operating log. In addition to the customary information usually contained in conventional operating log books, such as meter and instrument readings, maintenance records, and daily notes, *the log book should record any arcbacks, if they ever occur.* Most sealed-ignitron rectifiers never have arcbacks. However, arcback is a subject of importance to the maintenance man. An arcback is an operating disturbance resulting from electronic failure of the tube. The tube fails to hold back the current during the negative part of the voltage wave; and this failure allows short-circuit current to flow in the rectifier system. (See Fig. 9-9, showing paths of current during arcback.) This short-circuit current should be automatically interrupted by the power circuit breakers on both the a-c and the d-c sides of the rectifier. After arcback the breakers can usually be reclosed immediately and normal operation continued.

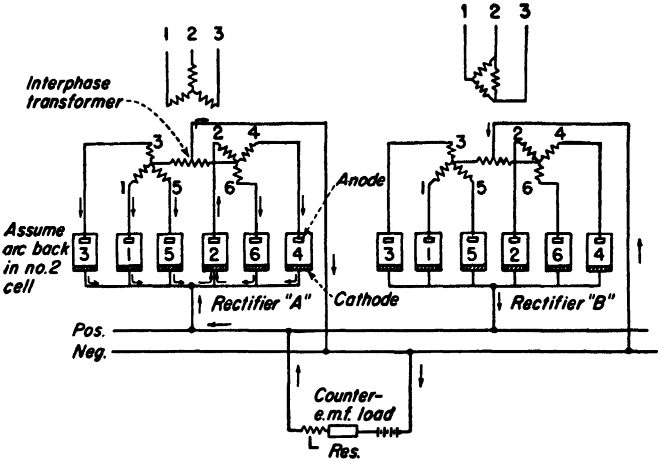


FIG. 9-9. Direction of current flow during arcback is shown by arrows.

The time and effort required to keep a record of any arcbacks that may occur are justified if the frequency of arcback becomes excessive. Acceptable arcback frequency varies for different applications, but in general anything exceeding more than two or three arcbacks for a single rectifier equipment per year should be investigated and, if possible, corrected. Since the subject of arcback reduction falls under the heading of trouble hunting, it will be referred to later on under that heading.

Care of Spare Tubes

The sealed tubes are expendable and replaceable. It is recommended that the user carry one or more of them so that he can quickly replace any tube which has reached the end of its usable life, and thus avoid an unnecessarily long interruption. These spare tubes should be stored near the rectifier in a clean, dry place. Each tube should be kept in a vertical position so that all the liquid mercury remains in the bottom of the tube. This is important, because if liquid mercury becomes attached to the anode, it may arcback when placed in service, whereas the arcback would otherwise be unnecessary. A good suggestion for helping to keep mercury off the anodes of spare tubes is to keep the upper part of the tube, particularly the seal and anode lead, warmer than the lower part of the tube. This can be done by placing a lighted electric bulb near the upper part of the tube. The heat from the lighted lamp will be conducted by the anode lead to the anode inside the tube. If the anode is kept warmer than the mercury at the bottom of the tube, it tends to keep mercury from condensing on the anode.

It is good practice to test the spare tubes at intervals of 6 months to make sure that they are always ready for instant operation. The best test is actually to operate the spare tube in the rectifier unit.

Many users follow the practice of rotating spare tubes with operating tubes every 6 months. There is no objection to this practice, and it does not invalidate the warranty of the tube. In other words, the 36-month operating warranty is based on the time the tube is installed in the equipment. When tubes are taken off the shelf and installed in service, they can be removed from the equipment later before the end of the 36-month operating period and placed back on the shelf, and later returned to service. The period while the tubes were back on the shelf is not considered part of the 36-month operating warranty, but, of course, it must be considered part of the 12-month shelf warranty.

Ignitors

It is advisable to test the operation of the ignitors occasionally, using the oscillographic method to determine whether the ignitors are firing easily or hard, or are perchance occasionally misfiring. For most rectifier installations, a small amount of ignitor misfire does not cause any harm or inconvenience, but experience has indicated that if an ignitor misfires more often than 5 to 15 times per minute, there is usually something wrong with it, and it will get worse very soon. On that basis, such ignitors should be retired from service. A complete description of how to make ignitor tests will be given under the section heading "Trouble Shooting."

Misfire

Sealed-ignitron tubes for rectifier service are frequently equipped with one or more spare ignitors. The spare ignitor is intended to permit operation to continue in case of mishap, such as reverse voltage burning off the tip, to the ignitor initially placed in service. If misfire develops and is not corrected by connection of the spare ignitor, the volt-ampere firing characteristics may be checked to determine whether the difficulty is in the ignitors or the excitation circuit.

There are three ways of quickly telling whether misfire is present during the daily inspection of the rectifier unit.

1. **Sound of the Transformer.** Rectifier transformers have two fundamental frequency notes present when there are interphase transformers used. The first is the deep note of the supply frequency, usually 60 cycles. The second is a multiple of the supply frequency which in the case of 6-phase, double-wye connections is usually three times 60 cycles, or 180 cycles. This gives a shrill high-pitched overtone. When everything is normal there is the steady sound of these two combined notes produced by the transformer. The level may be modified by the amount of rectifier load or by the amount of grid control. However, if misfire is present, it causes a distinct snapping or knocking sound which is readily distinguishable from the regular hum of the transformer. Therefore, if appreciable ignitor misfire is present, it can usually be easily detected by listening to the transformer.

2. **Glow inside the Tube.** Another way to check for ignitor misfire is to look for the absence of glow in the tubes when there is load on the rectifier. In some tubes the characteristic blue mercury-vapor glow may be seen through the glass anode seal. The glow can be seen more positively, however, through the glass ignitor seals at the bottom of the tube. Inspection for glow through these ignitor seals may be facilitated by using a small mirror on the end of an insulated handle. The tubes are electrically hot while under load; hence the insulated handle. If misfire is present, there will be periods when the glass seals are black. Otherwise, these seals have the characteristic blue-green color of the mercury arc.

3. **Action of the Ignition-checking Relays.** An induction disk-type relay having adjustable time lever setting is usually connected in the control circuit to detect misfire. If misfire persists for a definite time, the relay rings an alarm. When either of the above two checks indicates possibility of misfire, it can be confirmed by watching the disk of this relay through the transparent relay cover. The relay is so connected in the control system that ignitor misfires start to turn

the disk. If inspection shows that the disk is tending to turn and then return to reset position, it indicates that some tube is misfiring. Further details of the ignition checking circuit, and what to do in case of misfire are also included under the section heading "Trouble Shooting."

Tube Current Balance

It is pointed out in Table XIV that the performance of the tubes in respect to their sharing of the total rectifier load current should be watched, both daily and monthly. In general, the current through the tubes should be equal within ±10 per cent for loads above one-half of full-load rating.

FIG. 9-10 Measuring individual tube current with hook-on-type ammeter for an accurate test of tube current balance

For a quick check there are two methods. The first is to inspect the intensity of the arc glow as described in the previous paragraph. Complete absence of glow or significant differences in the intensity should be followed up to determine the cause. The second method is to measure the anode seal or lead temperature by thermometer. If the tube currents are balanced, these temperatures should be equal. Severe unbalance may be detected by noting the difference in radiated heat from these tube parts, placing the back of the hand near but of course not on the seal.

NOTE: The voltage of the anode is the so-called "peak inverse voltage." For single-way rectifier circuits this is usually slightly over twice the d-c output voltage. Therefore, when working around these tubes while they are electrically hot, suitable precautions should be observed.

If an accurate test of tube current balance is desired, the hook-on ammeter method is recommended (Fig. 9-10). A type using a split-core transformer with its secondary connected to a rectifier instrument through a range-selecting switch is desirable. The easiest place to measure the current is on the anode lead, but the instrument should have a well-insulated handle and the testing should be conducted carefully because of the aforementioned anode voltage. These hook-on ammeters do not read accurately either the average or the rms anode currents, because of the unusual wave shape of rectifier currents. They do, however, provide a means of determining percentage unbalance if the readings are all taken at any given rectifier load.

Procedures for remedying tube current unbalance, if it is observed during the regular inspection period, are given under the section heading "Trouble Shooting."

Pink-blue Tube Arc Color

In case the color of the arc, as observed during inspection, has a pinkish tinge instead of the normal blue mercury arc color, it indicates that the tube is leaky. Whenever such a tube is found, further tests for vacuum tightness, which will be described under "Trouble Shooting" should be conducted.

Tube Operating Temperature

The range of acceptable operating temperature (water-jacket temperature) of sealed-ignitron tubes is wide (usually 3 to 40°C). However, these limits may not be greatly exceeded before maloperation (usually arcback) results. During the daily inspection, it is therefore possible to tell quickly whether the temperature is within reasonable limits by feeling of the tube jackets while a person is standing on an insulating platform or rubber mat to protect himself from electrical shock.

The average operating tube temperature may well be tested by thermometer occasionally to make sure that the automatic valve, thermostatic relay, or motor-driven blower is adjusted to hold the desired tube temperatures. Rectifier units having raw-water cooling will have tubes operating at various incremental values between the incoming water temperature and the temperature setting of the automatic water valve. Although it is permissible for this difference to be as much as 37°C (40°C out and 3°C in), it is desirable to narrow the temperature rise of the water through the tubes down as much as possible without running the water rate up too much. Lowering the setting of the automatic water valve accomplishes this objective.

The other cooling methods all employ recirculating water pumps, and usually the water flows through the tubes in parallel. This permits all tubes to operate at approximately the same temperature. It is advisable to test the individual temperatures of all tubes while the rectifier is under load at least annually where recirculation is employed.

If there is a difference in any of the tube temperatures, it may mean unequal water flow through the tubes caused by accumulations in the water piping or cooling passages of some of the tubes. Such tubes then may run too hot and cause arcback, or shorten the tube life. Such obstructions to free water flow should be removed.

FIG. 9-11. Rear view of sealed-ignitron panel with cover plates removed. Shown are the firing-circuit components assembled and wired at upper and right-hand side, cathode current connections and part of water-cooling system at left.

Unless the water rate becomes excessive, it is best to keep the maximum tube operating temperature lower than 40°C (25 to 35°C is an ideal operating temperature range for sealed ignitrons).

The water temperature of the tube controls the mercury-vapor pressure inside. Water in the cooling jackets also removes the losses from the graphite anode. These losses are radiated from the graphite through the vacuum to the water-cooled surface inside the tube. For this reason the anode heats to a high temperature and often becomes cherry to red hot above half load. The red-hot anode may be seen by looking through the anode glass seal. It is perfectly normal operating condition.

This high anode temperature causes high anode seal and lead temperature, when substantial load is carried by the tube. Temperatures up to 250°C are acceptable. It is important, however, to prevent water from splashing, spraying, leaking, or dripping on these glass anode seals since it will cause them to shatter instantly when at such high temperature.

Thyratron Firing Tubes

In case thyratron tubes are used in the ignitor firing circuit, they deserve some attention during inspection. They should be examined for color; a pinkish blue in the glass grid seal indicates a leaky tube. If any sparkling particles can be seen moving around inside the tube it indicates low cathode emission. Low cathode emission may also cause ignitor misfire which is not explainable by any other reason. If the tube has no arc color or is stone-cold, it indicates a burned-out filament. Any of these symptoms call for a replacement tube. Most thyratron firing tubes should give 18 months or more tube life. Usually they have protecting fuses, and serious firing tube trouble usually causes burning of the associated fuse.

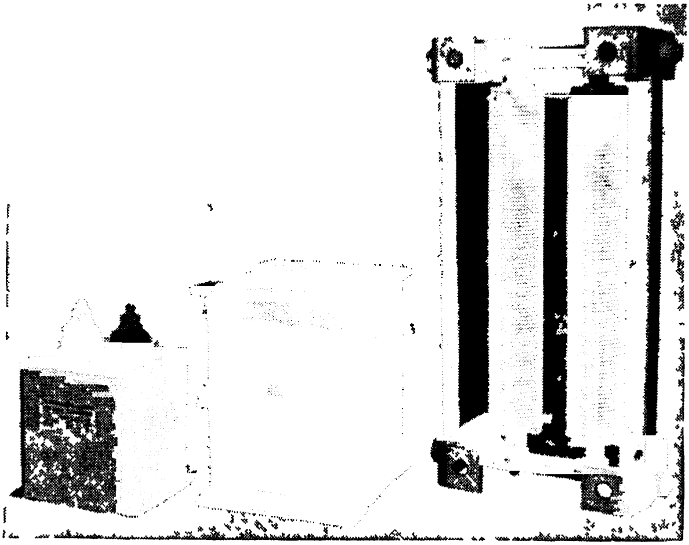


FIG. 9–12 Component parts of static magnetic-ignitron firing circuit. capacitor, saturable reactor. and wire-wound resistor

How to Care for the Excitation Equipment

There is little to do in connection with maintenance of the ignitor excitation equipment. For purposes of this discussion it is assumed that a magnetic excitation system of the type illustrated in Figs. 9-11 and 9-12 is supplied with the rectifier unit. Such a system consists of small, dry-type transformers, linear reactors, saturating and saturable reactors, capacitors, dry-plate rectifiers, and resistors so combined that they generate peaked positive voltages for the ignitors, holding voltage for the holding anodes, and also, provide a means for phase-controlling the rectifier output voltage.

The principal maintenance work is to keep them clean of dust or dirt so that they remain cool. It is also important to keep them dry, since moisture may cause insulation failure.

Regular monthly inspection should include an examination of the various dry-type transformers and reactors to see if they are running too hot under load conditions. Most of these devices have Class B type insulation so that temperatures up to about 110°F are permissible. The capacitors should be inspected for oil leaks and their temperatures should not exceed 40°C rise over ambient. If any of the devices are too hot, they should be replaced or else the recommendations of the manufacturer's field engineer obtained.

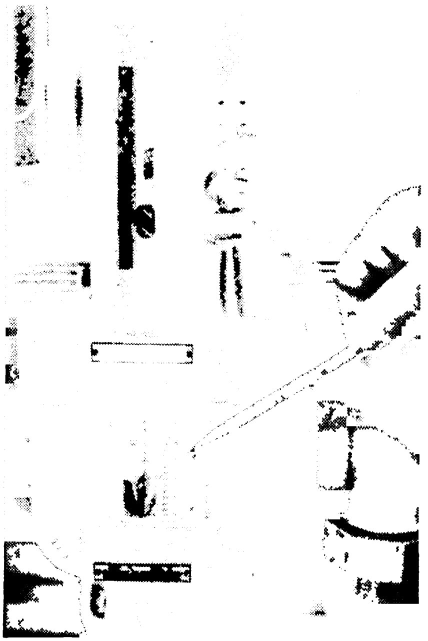


Fig 9-13 Scale on water-flow relay reads in gallons per minute The relay may be set to operate at different rates of water flow by simply adjusting pointer on upper part of relay

Dry-plate Rectifiers

The dry-plate rectifiers should have a very careful annual checking. This should include testing their operating temperature by thermometer. Selenium stacks should not exceed a maximum of 70°C, final temperature. Oscillograph tests should be made, looking for the presence of inverse current in the ignitor. The method of making this test will be described later. This is an advisable test as it indicates whether there are defective stacks in the dry-plate rectifier. Such defective stacks may cause the ignitors to burn off if allowed to continue in operation.

Visual examination of the stacks should include looking for two kinds of defects. The first defect is evidence of past overheating. On selenium disks this is indicated by a slumping, or bead of solder, on the underside of the disk. The second type of defect takes the form of burned spots on the disks. These will be small, rough, brownish blemishes at the junction of the pressure washers and the silvered selenium coatings of the rectifier disks. Such spots represent places where the selenium has shorted through and which may or may not have been burned open.

In some cases the individual disks may be tested with multimeter type ohmmeters. Each disk should be tested for d-c resistance in one direction and then repeated in the opposite direction. Two values of resistance for each disk should be obtained if the disks are normal and healthy, one many times higher than the other.

Trouble Shooting

It was stated earlier in this chapter that troubles rarely occur with sealed-ignitron rectifiers. It is desirable that this point be again emphasized. Furthermore, the rare cases of trouble can be diagnosed and remedied easily on such electronic equipment because they are fundamentally simple. The maintenance man should, however, understand the equipment and be forewarned of the possible troubles that may develop, if he is to take full advantage of this simplicity. The following should equip him with the needed information concerning these troubles; and thus the user will be assured of obtaining from the rectifier the maximum of reliable service.

Fig. 9–14. Testing dry-plate rectifier stack from ignitron firing circuit. Resistance of each disk should be measured separately making two tests for each disk, reversing the polarity. Good disks will measure nearly infinite resistance in one direction and less than 100 ohms in the opposite direction.

While apparatus trouble is always a matter of concern to the operating department, to a maintenance man it often has its appealing aspects. In fact, to a good maintenance engineer, finding and correcting trouble in electric apparatus have the same appeal that an unsolved crossword puzzle has to a confirmed addict of this pastime.

Hunting trouble is the proving field wherein the maintainer's self-preparation, experience, and native ingenuity are tested. It gives him an opportunity to exercise his imagination, too—but for practical objectives. Usually hunting for trouble also carries with it the excitement of a race, because the maintenance man must pit all his facilities and resourcefulness against the demands of the operating department to return the equipment to productive service in the shortest possible time.

Test Instruments

The question of what test instruments should be available is always important. Usually the maintenance man, who invariably has a natural liking for an array of fancy instruments, will want more than are really justified. There are, however, a minimum number which should be available:

1. **Oscillograph.** Either string galvanometer-type instrument or cathode-ray oscilloscope is satisfactory. However, the cathode-ray type is much less expensive. There are many grades of such instruments, the price depending principally on the size of cathode-ray tube screen. Any one of the different sizes is useful, but the larger the screen the better.
2. **Analyzer.** An analyzer is a multimeter instrument containing circuits that can be selected for measuring volts, ohms, and amperes.
3. **Homemade Magnetic Links and a Compass.** The combination of homemade magnetic links and a compass is used for measuring surge currents through the tubes when looking for the faulty tube in cases of frequent arcback. The magnetic links can be made from ordinary hack-saw blades. About 12 pieces of hack-saw blade, each 1½ in. long, should be prepared. Then each should be coated at one end with white paint, to indicate polarity.

Following is a list of instruments suitable for ordinary maintenance work on even the largest installation of sealed-ignitron rectifier equipments. (It should be understood that this list does not contain test equipment for maintenance and servicing the transformers or switchgear, nor does it contain apparatus for determining withstand voltage levels):

1. A-c voltmeter, 600 volts.
2. A-c ammeter, 5 amp.
3. Analyzer.
4. Hook-on ammeter. It should be capable of reading currents up to 600 amp, rms.
5. Oscillograph. When a cathode-ray instrument is used for testing rectifiers, certain accessories should be available. Potential dividers of the type shown in Figs. 9-15 and 9-16 are useful. An ordinary cathode-ray oscillograph is not designed for observing d-c voltages because a protective capacitor is connected in series with the input-signal circuit. This internal capacitor should be reconnected so that

it will be used only in the test circuit when the amplifier is used. In most cathode-ray oscillographs the amplifier is designed for a-c operation only. If the maintenance technician does not understand how to modify the circuit of the cathode-ray oscilloscope so as to read d-c voltages, instructions should be obtained from the manufacturer. (Refer to Chap. 3 for additional information on this subject.) Furthermore, some cathode-ray oscillographs do not have facilities for synchronizing the sweep wave with the input (usually 60-cycle) supply voltage. In these instruments changes may be made so that the sweep voltages are taken from the 6-volt tube heater circuits. The internal synchronous sweep circuit should be open-circuited when the 60-cycle sweep is applied so that two synchronous signals will not be applied simultaneously to sweep circuit.

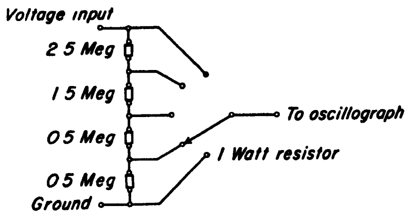


FIG. 9–15. Potential divider circuit for oscillograph input.

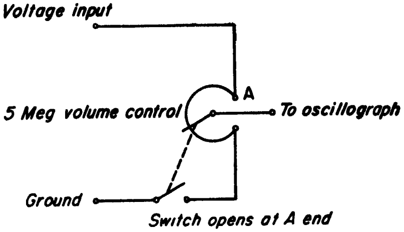


FIG. 9–16. Another potential divider circuit for oscillograph input.

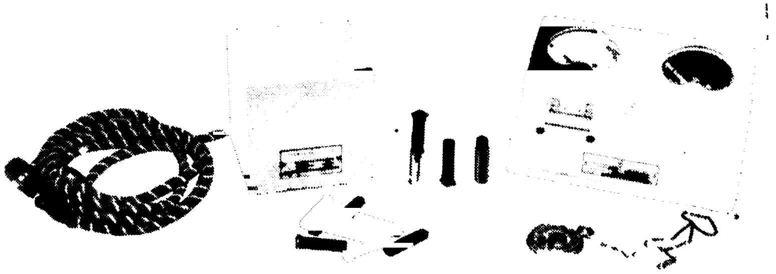


FIG. 9–17. Demagnetizing coil, surge-crest magnetic links, and surge-crest ammeter are very useful instruments in test work.

6. Surge-crest magnetic links, surge-crest ammeter, and demagnetizing coil. These instruments are commercial versions of the homemade hack-saw blade, magnetic links, and compass described previously (Fig. 9-17).

7. Other devices to aid in quickly locating control-circuit opens and shorts such as bell ringers and neon-tube voltage testers.

Observation of Normal Instrument Readings and Wave Shapes

A good way to prepare for rapidly locating possible trouble is to have complete records on what the normal voltage and current readings and wave shapes are in the various parts of the main rectifier power and control circuits. Obviously, most electrical troubles cause abnormal wave shapes in the power rectifier circuit, and, if the maintainer has records available showing what the normal conditions are, it is a simple matter to compare abnormal observations with them and thus determine the exact location of any trouble.

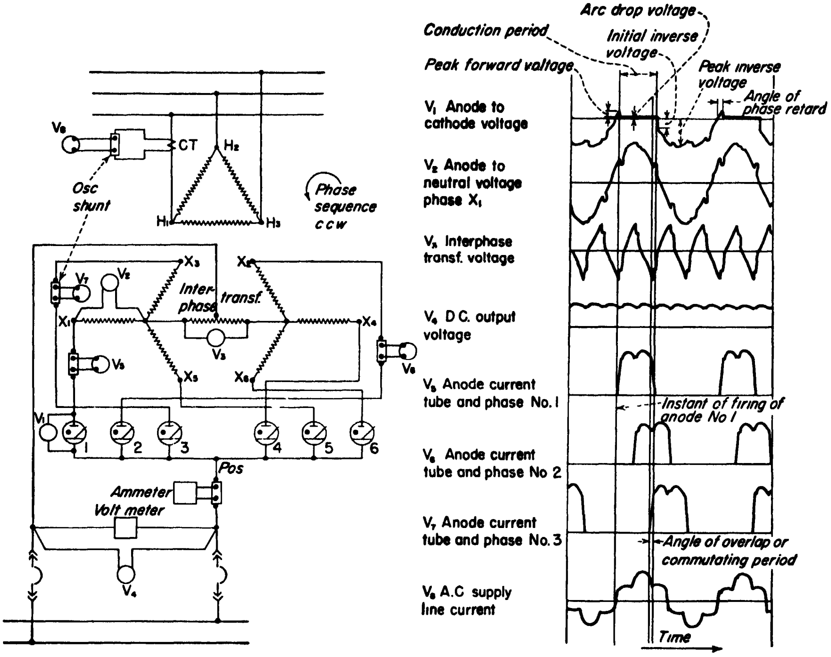

Arc drop voltage
Conduction period
Initial inverse voltage
Peak forward voltage
Peak inverse voltage
Angle of phase retard
V_1 Anode to cathode voltage
V_2 Anode to neutral voltage phase X_1
V_3 Interphase transf. voltage
V_4 D C. output voltage
V_5 Anode current tube and phase No. 1
Instant of firing of anode No 1
V_6 Anode current tube and phase No 2
V_7 Anode current tube and phase No. 3
Angle of overlap or commutating period
V_8 A.C supply line current
Time
V_8
CT
H_2
Osc shunt
H_1
H_3
Phase sequence ccw
X_3
X_2
V_7
V_2
Inter-phase transf.
X_1
X_4
V_3
V_5
X_5
X_6
V_6
V_1
1
2
3
4
5
6
Pos
Ammeter
Volt meter
V_4

FIG. 9-18. Delta six-phase double-wye rectifier power circuit showing principle wave shapes obtained. It is extremely important that the trouble shooter be thoroughly familiar with all normal wave shapes so as to recognize immediately an abnormal condition.

As an example, Fig. 9-18 shows the popular delta, 6-phase, double-wye rectifier power circuit and the normal wave shapes in important parts of the circuit as they would be observed by oscillograph. If the power circuit of the rectifier equipment, which is under the care of the maintenance technician, is not the six-phase, double-wye, normal wave shape records for various parts of the circuit should be made for subsequent possible use in case of trouble. The trouble shooter should practice the use of the oscilloscope enough to be capable of handling it efficiently when the need arises.

It is always good practice to insulate the cathode-ray oscillograph from the 110-volt service connection that is used for supplying its excitation, by means of a small 1:1 ratio insulating transformer. This is because, when the cathode-ray oscillograph is used to measure rectifier-circuit voltages, the instrument may be exposed to higher voltage than its internal insulation can withstand. Test leads should be attached to insulating handles to protect the person who holds the leads during any measurement (Fig. 9-19). Most cathode-ray oscillographs have about 200-volt a-c full-scale screen deflections. Therefore, potentiometer circuits such as illustrated in Figs. 9-15 and 9-16 should be added when the voltage to be measured exceeds 110 volts.

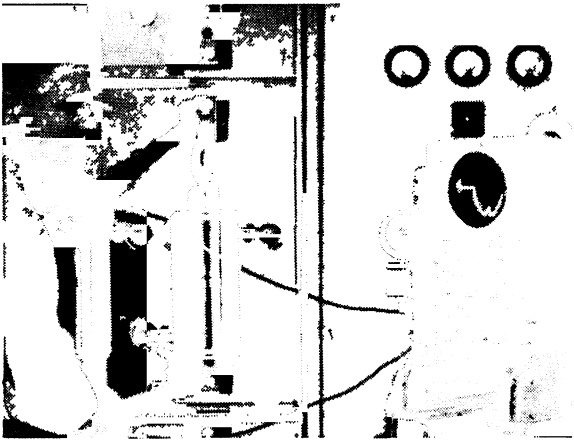


FIG. 9-19 Test leads are attached to insulating handles for safety.

When oscillographic observations of current are made, it is necessary to use a shunt. This shunt can be any noninductive conductor producing a voltage drop of 50 to 100 mv when the current to be measured is passed through the shunt. The oscillograph leads should be carefully twisted all the way from the center of the shunt to the instrument terminals to avoid inaccuracy from magnetic pickup by the leads. The amplifier circuit must be turned on when measuring currents in order to obtain reasonable deflection on the screen.

Wave shapes shown in Fig. 9-18 illustrate rectifier operation with a moderate amount of phase control. The triangular peak of voltage identified by the words "peak forward voltage" on trace V_1 is always observable when there is any phase retard. If the rectifier were running fully advanced, the flat line, identified by the words "arc drop voltage" would extend all the way across the positive part of the wave, and there would be no so-called "peak forward voltage" triangle.

It is sometimes desirable to be able to estimate quickly the amount of phase control. This can be done by measuring the "rectified d-c output volts" by means of a d-c voltmeter, and the magnitude of "peak forward voltage" and "peak inverse voltage," as illustrated by the trace of anode-to-cathode voltage V_1, Fig. 9-18 under the same operating conditions. These values should then be substituted in the following formulas:

$$\text{Cosine angle of retard} = \frac{\text{peak forward voltage}}{\text{peak inverse voltage}}$$

$$\text{Maximum output volts} = \frac{\text{rectified d-c output volts}}{\text{cosine angle of retard}}$$

$$\text{Per cent phase control} = \frac{\text{maximum output volts} - \text{rectified d-c output volts}}{\text{rated d-c output volts}} \times 100$$

In addition to making reference records of the rectifier wave shapes indicated in the foregoing, it is desirable to record measurements by means of portable test instruments of the normal voltage and current relationships in the rectifier power circuit. Study of the wave shapes in Fig. 9-18 will indicate that ordinary portable testing instruments should not be used to measure some of the circuit voltages and currents. For instance, there is no indicating instrument to measure anode-to-cathode voltage and give results that mean anything. Ordinary a-c voltmeters, however, can be used to measure anode-to-neutral voltage, interphase voltage, transformer primary voltage, etc. Transformer primary currents can also be measured by standard instruments. As previously stated, the hook-on type ammeter may be used for anode current study only because it indicates relative tube current balance. The numerical magnitudes of these hook-on ammeter anode measurements are neither average nor rms values.

Locating and Correcting Troubles in Sealed-ignitron Rectifiers

Arcback Interruptions

An arcback is a failure of rectifying action which results in the flow of a principal electron stream in the reverse direction, because of the formation of a cathode spot on an anode. When such an event occurs, there is a short-circuit a-c current and usually a reversal of d-c current flowing from the rectifier. These high currents trip both the a-c and the d-c power circuit breakers, disconnecting the rectifier, or when high-speed anode breakers are used, disconnecting the offending tube from the systems. Usually the breakers may be reclosed at once, either manually or automatically, and normal service restored.

Arcbacks are more likely to occur on higher d-c voltage rectifiers than on low voltage. For instance, arcbacks on 125- or 250-volt rectifiers are rare, but they may be expected occasionally when the same tubes are used for 600 volts. Likelihood of arcback is increased for prolonged overload. Several other factors may tend to cause arcback, and these will be discussed in detail later.

When the end of usable tube life is caused by arcback, such arcbacks usually occur directly the rectifier is placed in service after it has been out of service for some time. In this respect tube failures are often like incandescent lamp burnouts. It is well known that most electric lamps burn out at the very instant they are turned on. This characteristic is fortunate, for it means that in the case of ignitron tubes the operator will usually be close at hand and the rectifier can, therefore, be placed back in service soon or the tube replaced quickly as a result.

The amount of overcurrent that flows during arcback is large. In the a-c lines supplying the primary of the rectifier transformer, values as high as fifteen to twenty times normal may be encountered. Overcurrent through the tubes themselves varies, depending on whether or not power can feed back through the faulty tube from the d-c system. Arcback current through faulty tubes has been measured at from twenty-five to ninety times normal, depending on the d-c voltage level and amount of d-c feedback. Current in the normal tubes, which also, of course, contribute current to the faulty tube (see Fig. 9-9) may reach twenty to thirty times normal.

Obviously it is essential that the protective switchgear interrupt such high current as rapidly as possible. When semi-high-speed switchgear is employed, the d-c breakers should open in not longer than 0.03 to 0.05 sec and the a-c breaker within 0.15 sec. Semi-high-speed switchgear is usually adequate for sealed-ignitron rectifiers. In cases where, for special reasons, it has been necessary to supply high-speed switchgear, the breakers should start current reduction in approximately 0.016 sec. The maintenance man should always see that the overcurrent relays and power circuit breakers are adjusted and calibrated to achieve the functional operation specified by the manufacturer, which will usually conform to the above rules.

Arcback Caused by Leaky Tubes

One important cause of arcbacks is leaky tubes. There are several ways of determining whether tubes are leaky:

1. Leaky tubes may sometimes be identified during operation by an unusual pinkish tinge in the otherwise characteristic blue-green color.

2. If a particular tube is suspected, it may be removed and a "click test" applied. This consists of rocking the tube back and forth and listening for the click or impact of the mercury when it splashes about in the tube. If air or gas is present it will cushion the impact and no click will result.

3. A test similar to (2) consists of inverting the tube, thus letting the mercury run into the glass anode seal. If this traps any bubbles that escape past the glass, it indicates the presence of air or gas. A tube that has had this test applied to it may arcback a few times when it is first returned to service.

4. Occasionally leaks are produced by cracks in the glass seals which are large enough to be observable, if carefully inspected.

5. A high-frequency spark coil will indicate gas in the tube. The device should be adjusted to give a spark ½ in. long. Then the pointer should touch the glass anode seal midway between the metal parts, and if gas is present it will produce a glow in the tube.

6. The best test is a high potential test. A high-reactance ignition-type test transformer capable of 12,000 volts rms should be used and a 25.0-ma ammeter connected in series with 10,000 ohms in the high-voltage leads to the tube. One lead goes to the anode, the other to the cathode. Voltage is increased rapidly to 12,000 volts. Even good tubes may break down or clean up for an instant. However, if at any time the milliammeter reads substantial current for more than 5 sec, the tube may be classed as gassy or leaky. A good tube should withstand 12,000 volts, 60 cycles for 1 min. Gassy or leaky tubes should be replaced when detected.

Arcback Caused by High Vapor Pressure

Experience has proved that arcback sometimes occurs when the mercury-vapor pressure is too high. The pressure of the mercury vapor in the tube depends on the water temperature, the pressure doubling for every 10°C increase in water temperature. It may also increase because of overload when the load is so high that the arc losses exceed the cooling ability of the water jacket.

Arcback is to be expected when vapor pressure exceeds values corresponding to 80°C or when long periods of overload exceeding 50 per cent are encountered. Therefore, in case of unexplained arcback, the operating conditions should be carefully examined by the maintenance man to be sure that overtemperature or overload is not the cause.

Arcback Caused by Dirt in Tube

One theory of the cause of arcback is that a small particle of insulating material 10^{-6} cm in diameter or less in size is attached to the anode. This particle, under the right conditions, may become so charged by the surrounding ionized plasma that a high enough potential gradient exists between it and the anode to draw out electrons from the anode surface. Such an event reverses the flow of electrons and becomes an arcback. Therefore, when a tube becomes dirty internally from long use, excess overload, combined excess overload and phase control, or simply by accident, it is likely to arcback. Such tubes must be replaced.

Arcback Caused by Excess Phase Control

Tests have proved that arcback probability is increased in proportion to the product of the peak inverse voltage times the rate of change of current at the end of commutation. The magnitude of this product increases rapidly when the amount of phase control is increased. Therefore, under certain combinations of load and excess phase control, arcback may result. When unexplained arcbacks are occurring investigation for this possibility is in order.

How to Identify a Tube That Is Causing Arcback

There are several methods of identifying a faulty tube. These vary from simple inspections of the tube to carefully carried out tests. A description of these methods follow:

Inspection of the Tubes. Sometimes faulty tubes can be picked out of the group at a glance. There are two telltale indications to look for. One is the pink-blue color of the arc, which indicates leakage and which has been described previously.

The other indication is for one of the tubes to have a dense dark coating on parts of the inside of the glass anode seal. Ordinarily, this coating does not develop unless a tube has arced back frequently, passing high arcback current.

NOTE: A uniform over-all darkness of the glass seal does not necessarily mean defective quality of the tube.

Trial-and-error Tube Replacement. Often the faulty tube can be weeded out of the group by a trial-and-error tube-replacement schedule, using one or more of the spare tubes. The more spare tubes used, the sooner will the faulty tube be eliminated.

First, the records should be examined to determine the prevailing frequency of arcback. Then a tube or tubes picked at random from the group of tubes in the rectifiers are replaced by tubes from the spare stock. These tubes should be new or, if not, have established performance records free from arcback.

Operation should then be watched for a sufficient length of time to find out by comparison with the previously established arcback frequency rate whether or not there has been improvement.

By proceeding to rotate the tubes from position to position in this manner, usually a change in arcback rate can soon be associated with some particular tube. This tube should be permanently replaced.

Magnetic Links and Surge-crest Ammeters. The magnetic-link method makes use of the fact that the extremely high arcback current is in the reverse direction from normal. The commercial type of magnetic links are high-grade permanent magnets made of cobalt steel. When placed near a conductor carrying 300 to 70,000 amp, they become magnetized in proportion to and in the direction of the current flowing in the conductor. A reading of the magnetic link is taken by placing the link in the test clip of the surge-crest ammeter, where both the magnitude of the current surge and its direction are indicated.

When used as arcback indicators, the links are placed near the anode cables or anode terminal of the tube with ½- to 1½-in. separation (Fig. 9-20). It is advisable to use a suitable metal clip to hold the distance between link and cable fixed. The magnetic links have red compound at one end only to indicate polarity, and all links should have the red ends pointing magnetically in the same direction for all tube positions.

After an arcback, the links should be removed before returning the rectifier to service. As the links are taken from the anode cables, they should be placed in magnetic shields numbered to correspond with the tube position from which the link was removed. The links are then tested in turn with the shields off (Fig. 9-21).

Failure of Tubes to Conduct Properly

The actual detection of tubes that are failing to conduct properly usually comes during regular inspection of the rectifier. Telltale indications of improper conduction, such as noise in the transformer, absence of tube glow, unequal anode, or seal temperatures of the various tubes, have been covered. Also previously mentioned was how final confirmation of this type of trouble could be obtained by means of hook-on ammeter readings. The oscilloscope may also be used to detect which tube is not conducting when trouble of that sort is suspected. Therefore, it remains only to analyze the causes of, and indicate the correction for, improper tube conduction.

There are three different categories of failure to conduct: (1) complete failure of the tube to carry current, (2) partial failure resulting from ignitor misfire, and (3) steady unbalance of current between the various tubes.

Complete Failure to Conduct

Infrequently a tube will be found that is completely dead; *i.e.*, it carries zero current when all the other tubes in the rectifier are loaded. Causes for this condition usually may be traced to one of the following:

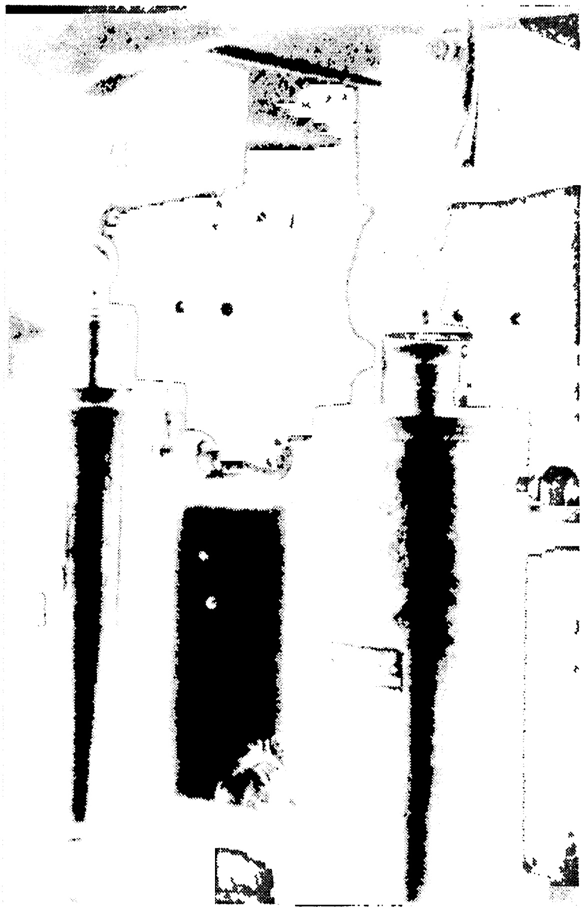


FIG 9–20 Magnetic links are placed near anode for arcback indicators.

Broken or Loose Ignitors. The ignitor points are attached to steel supporting rods. Sometimes the mercury in the tube is splashed against the ignitor, because of carelessness in handling the tube. This may cause the ignitor point to break off or come loose at the point where it is supported. If resistance or bell-ringer tests show that the ignitor circuit is completely open inside the tube, it may be assumed that the type of fault described above exists.

Ordinarily the spare ignitor is mechanically intact in such a tube, and the connection to the ignitor can be transferred from the faulty ignitor to the sound one. The fact that the broken ignitor point is floating on the mercury will not usually cause any difficulty.

Ignitors Burned Off. Ignitors may also be burned off by reverse current through the ignitor. Reverse current may flow if the dry-plate rectifier or electronic tube in series with the ignitor (in the excitation equipment) is defective. Sometimes wrong electrical connections are made and an a-c voltage is connected to the ignitor by mistake. In any event, tests should be made to determine whether the possibility of reverse current exists, whenever an open ignitor is found. Sometimes reverse current does not completely burn off the ignitor. Instead it damages it and causes hard firing.

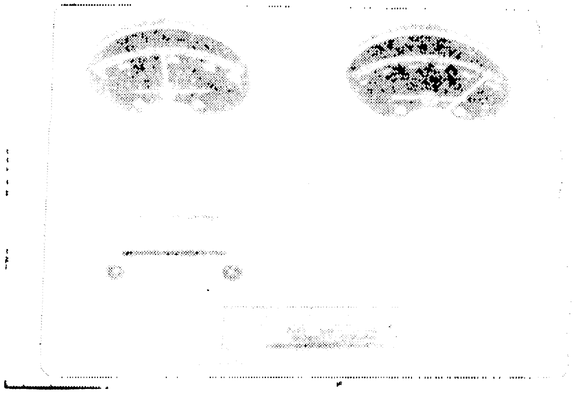


FIG. 9-21. Magnetic links are placed in surge-crest ammeter for reading.

Trouble in the Firing Circuit. Failure of firing-circuit components may cause one or more tubes completely to fail to conduct. The tests to determine the cause of such firing-circuit trouble are covered later under "Ignitor Misfire."

Tube Filled with Air. If a tube fills completely with air, it will not conduct. The tests for leaky tubes described previously may be employed. When a tube has air in it, current will flow through the ignitor but the ignitor will not fire. This condition can be tested by observing the voltage by means of the oscilloscope between the holding anode terminal and the cathode of the tube while the rectifier is carrying the load. If there is much air in the tube, the holding anode fails to conduct.

Open Circuit in Rectifier Transformer. If no other reason can be found for complete failure to conduct, the main rectifier transformer should be tested to see if the secondary winding associated with the faulty tube has an open circuit.

Ignitor Misfire

Ignitor misfire is characterized by intermittent failure of a tube to carry current. Nearly all ignitron rectifiers misfire occasionally. There is greater tendency to misfire when the ignitors are cold. For most applications this is not objectionable as its only effect is to cause a slight reduction in the output voltage for a single cycle.

Ignitor Misfire Detection System

Sealed-ignitron rectifiers are usually supplied with misfire detection equipment. Figure 9-22 shows the elementary diagrams of two circuits often employed. Figure 9-22A is used with six-phase, double-wye transformers. When misfire occurs a subharmonic voltage (one third of normal interphase frequency) appears across the interphase transformer. The reactor, capacitor, and coil of a time-delay induction relay are tuned to resonance at this abnormal frequency, so that misfire causes the relay to start closing its contacts. If the misfire persists for a definite time (approximately 10 sec), the relay contacts close and light a signal or ring an alarm.

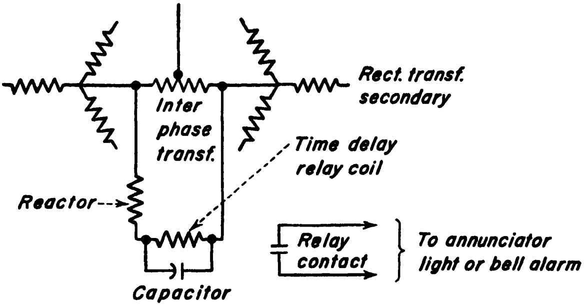
The Fig. 9-22*B* circuit is used with 12 tube combinations where two tubes normally conduct simultaneously. In such circuits, when one tube fails to conduct its companion tries to carry the load of both tubes; therefore, no subharmonic appears in the interphase transformer. Small current transformers, with their secondaries in series, are so connected that when all tubes conduct properly the current transformer secondary voltages cancel each other. If one tube fails to conduct, a definite voltage appears which operates the relays, and signals or alarm. Other schemes, which use relays or electric light bulbs to detect abnormal ignitor or holding anode voltage in case of misfire, are sometimes used.

These schemes are all based on the principle that a small amount of misfire is acceptable; hence the time-delay relay gives alarm only when persistent misfire exists.

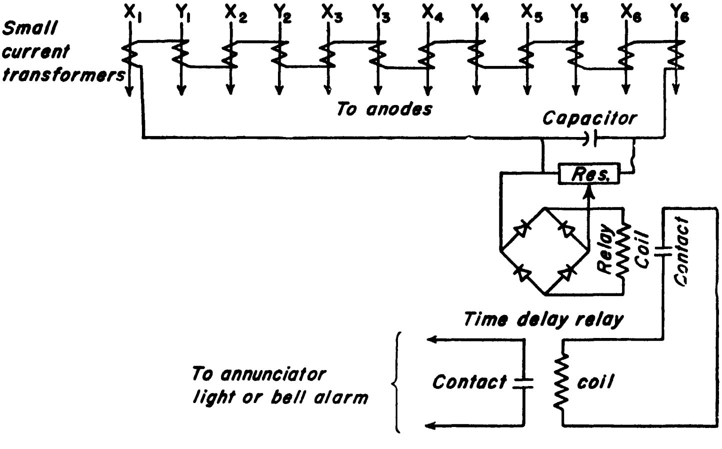
Wet Ignitors

One of the most common causes of ignitor misfire is ignitor wetting. A good ignitor should not become wet by the mercury in which is it immersed. However, when impurities such as gold, silver, copper, aluminum, nickel, and iron, inadvertently get into the mercury, they tend to cling to the ignitor and coat it. If the boron carbide of the ignitor becomes coated, mercury will tend to wet the surface instead of being repelled.

A wet ignitor requires increased firing power for successful ignition, depending on the area of the patch on the ignitor that has become wet. Depth of immersion of the ignitor varies during normal operation because of the ripples on the mercury pool surface. This condition creates a statistical likelihood of the mercury covering or uncovering



(A) Circuit used with 6 phase double wye transformer


Small current transformers
X_1 Y_1 X_2 Y_2 X_3 Y_3 X_4 Y_4 X_5 Y_5 X_6 Y_6
To anodes
Capacitor
Res.
Relay
Coil
Contact
Time delay relay
To annunciator light or bell alarm
Contact
coil

(B) Circuit used with 6 phase quadruple or parallel double wye transformer

FIG. 9–22. Elementary diagrams of two often-used circuits for detection of misfire in rectifiers.

patches of an ignitor which will wet, and thus causes ignitor misfire which has an intermittent characteristic.

The best way to find out if an ignitor is wet is to remove the tube from the rectifier and connect an ohm analyzer between ignitor and cathode. If the ignitor is wet, a place is found where the resistance does not change when the mercury is raised and lowered as the tube is tilted at various angles. If it misfires in some positions but not in others, the conclusion can be drawn that wetting is present.

The spare ignitor may be tried after a wet ignitor is discovered. Usually good operation will not continue long on the second ignitor as the primary cause of wetting usually will tend to affect both ignitors.

High-resistance Ignitors

Sometimes ignitor resistance characteristics gradually become so high that misfire results. Such misfire shows up in the oscillograph observations as characteristic tendency toward late firing.

Faulty Ignitor Firing Circuit

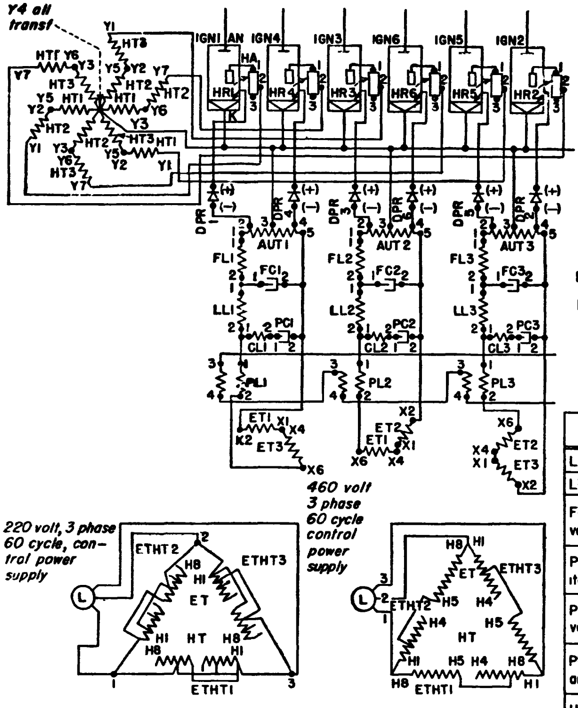
It is seldom that trouble develops in the magnetic type of firing circuits usually supplied with sealed-ignitron rectifiers. However, the following is a description of the normal behavior of a typical magnetic firing circuit, to prepare the maintenance man fully for all eventualities.

Principle of Operation

It will be noted that the three single-phase firing circuits (Fig. 9-23*A*) can be each divided into five functional portions as follows:

1. Holding anode excitation (obtained from the "Y" secondary windings) of the control power supply transformers.
2. Dry-plate rectifiers (DPR) which rectify the current flowing to the ignitor.
3. Peaked-voltage wave-shape generating circuits comprised of components *AUT*, *FL*, *FC*, and *LL*.
4. Angle of phase control for adjusting output d-c voltage consisting of d-c saturable reactor *PL*, linear reactor *CL*, and capacitor *PC*.
5. Control power transformer *HT* with phase-shifting windings *ET* for phasing the ignitors in approximately the correct vector position with respect to the anodes.

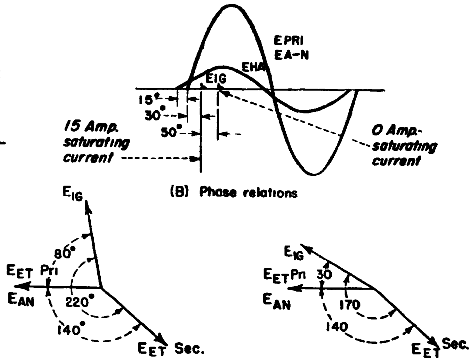
Each single-phase firing circuit fires two ignitors at 180-electrical-degree intervals. (For instance, the ignitors in tubes 1 and 4 are fired at 180-deg. intervals each cycle.) In order to follow the principles of operation, assume a positive half-wave voltage at the *X*6 terminal of winding *ET*3. This positive voltage appears across reactors *PL*, *LL*, and at terminal 2 of *FL* and terminal 1 of *FC*. The capacitor starts to charge in the positive direction at terminal side 1. Self-saturating reactor *FL* presents an impedance which at first allows only a trickle of current to flow through the dry-plate rectifier to the ignitor. However, as the positive voltage increases and the capacitor charges, the iron in reactor *FL* suddenly saturates and its impedance decreases to a low value. Capacitor *FC* quickly discharges its stored energy through *FL*, *DPR*, and the ignitor, causing the ignitor in tube 1 to fire. The proportions of the circuit are so designed that the



Primary connections for ETHT 1,2 and 3 transformers for parts 1,2,3

Primary connections for ETHT transformers 1,2 and 3 for part 4

(A) Elementary diagram of typical ignitor firing circuit



(B) Phase relations

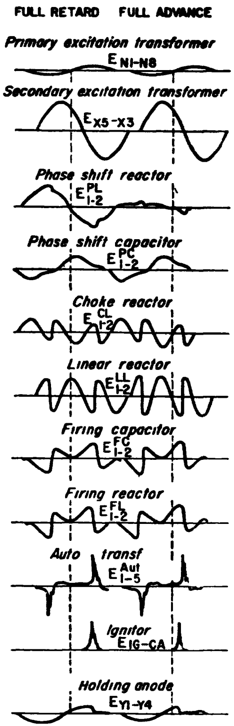
0 amps D-C saturating current–full retard

CIRCUIT ELEMENT	PHASE 1	PHASE 2	PHASE 3
Line volts A-c	220	220	220
Line amps A-c	346	346	350
Firing capacitor volts A-c	406	402	408
Phase-shift capacitor volts A-c	397	397	399
Phase-shift reactor volts A-c	326	339	327
Phase-shift reactor amps A-c	079	0.79	079
Holding-anode resistor volts 14 ohms	129 131	134 135	132 132

152 amps D-C saturating current–full advance

CIRCUIT ELEMENT	PHASE 1	PHASE 2	PHASE 3
Line volts A-c	220	220	220
Line amps A-c	348	346	349
Firing capacitor volts A-c	440	438	437
Phase-shift capacitor volts A-c	412	416	414
Phase shift reactor volts A-c	53	55	53
Phase-shift reactor amps A-c	0.77	0.78	0.77
Holding-anode resistor volts 14 ohms.	231 238	242 245	244 242

(C) Representative voltages and currents



(D) Comparative wave shapes

FIG. 9–23. Typical ignitor firing circuit, voltages, currents, and wave shapes.

energy stored in the capacitor will be discharged in a short time, approximately 15 to 20 electrical degrees, which gives rise to the short-duration impulses shown in Fig. 9-23*B*, E_{IG}. One hundred and eighty electrical degrees later, the ignitor in tube 4 is fired in a similar fashion.

Figure 9-23*B* shows that timing of peaked wave impulses E_{IG} can be adjusted over an approximately 50-deg electrical range by adjusting the saturating current from 0 to 1½ amp. Increasing the d-c saturating current advances the instant of firing in time phase with respect to the main anode voltage. This phase shift is brought about by adjusting the d-c saturating current and consequently the reactance of *PL* which is the variable element of the reactance, capacitance-type phase-shifting bridge circuit consisting of *PL*, *CL*, and *PC*.

Normal Behavior of Firing Circuits

Figures 9-23*C* and 9-23*D* are tabulated data applying to the typical ignitor firing circuit shown in Fig. 9-23*A*. In case of firing circuit trouble, oscillograph and instrument tests may be made, and the data obtained compared with the information shown in Fig. 9-23. From the comparison it should be possible to determine quickly the location of the trouble. When the rectifier, for which the maintainer happens to be responsible, has a different firing circuit than the one illustrated, it is advisable for him to make similar records to establish the normal behavior of his rectifier. Then if he ever has any trouble, he will be prepared.

If trouble occurs in such components as reactors, capacitors, or control power transformers, the defective part should be replaced with a new one as quickly as possible. If it develops in the dry-plate rectifier, and the d-c ohmmeter test described earlier cannot be used, then it may be necessary to make a current test to establish the degree and exact point of failure. One way to make a current test is to insert an oscillograph shunt in series with the dry-plate rectifier and observe the wave shape of the current through the rectifier. A defective dry-plate rectifier will allow substantial current to flow during both positive and negative half-waves. A good dry-plate rectifier will not allow discernible negative current to pass.

Ignitor Firing Requirements

Ignitors may be classified into three categories, depending upon the volts and amperes required to cause them to fire: easy-firing ignitors, hard-firing ignitors, and ignitors that misfire. It is necessary to watch the screen of the oscillograph, observing ignitor voltage for periods up to 1 min or more, to classify the ignitors. An easy-firing ignitor should not require more than 75 volts peak to fire. A hard-firing ignitor requires 75 to 250 volts to fire. Ignitors that misfire usually draw more current than normal ignitors and, as the regulation of the firing system is appreciable, the voltage observed when an ignitor misfires can be anything from 15 to 400 or 500 volts.

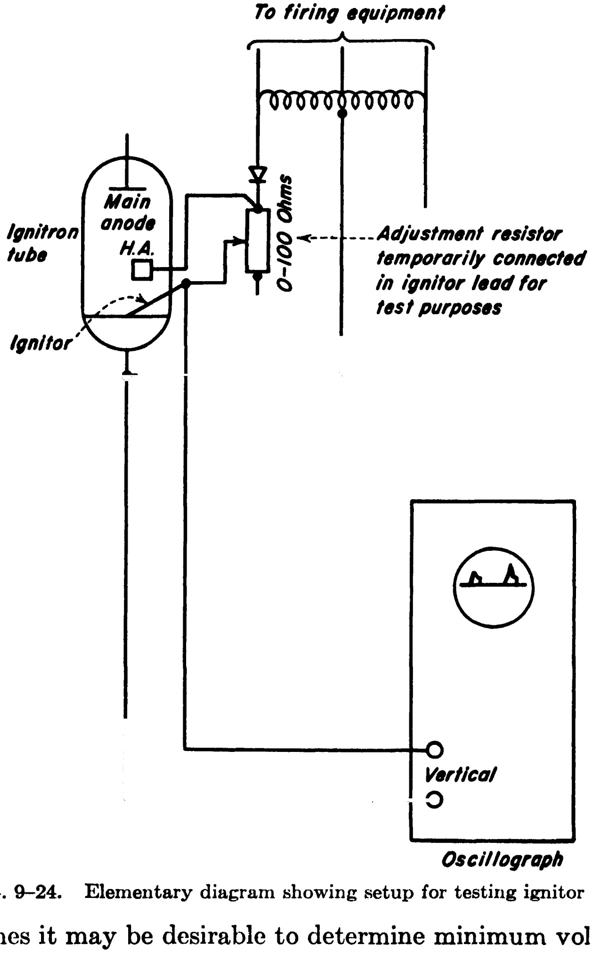


FIG. 9-24. Elementary diagram showing setup for testing ignitor firing.

Sometimes it may be desirable to determine minimum volt-amperes required to fire successfully a given ignitor (Fig. 9-24). Before making the tests the 0-to-100-ohm resistor shown in Fig. 9-24 should be calibrated so that the resistance of each of the buttons is known. Starting with the resistor on the zero end, it should be increased gradually until the ignitor being tested starts to misfire. Then make the following measurements:

1. Measure the voltage from ignitor terminal to cathode.

2. Connect the oscillograph to observe and measure the voltage across the portion of the resistor through which the current to the ignitor is passing. (The voltage under misfiring conditions should be measured.)

3. Measure the total voltage across the resistor and ignitor. (The sum of the two voltages measured under items 1 and 2 should be equal to this last measurement, serving as a check on the accuracy of the tests.)

4. Divide the voltage measured across the resistance by the calibrated value of the resistor at its setting. This result gives the ignitor firing current.

5. Item 1 is the voltage required and item 4 is the current required. From these two figures the volt-ampere characteristics of the ignitor are known. (The voltage should not exceed 300 and the current 40, for acceptable ignitors.)

Unbalanced Tube Currents

The existence of a current unbalance between tubes is rarely detected except by means of the hook-on ammeter. The effect of unequal current between various tubes is to overload some of them, thereby producing a tendency toward arcback or shorter tube life if the rectifier is very heavily loaded.

The most usual cause of tube-current unbalance is unequal arcdrop in the various tubes in the rectifier. The arcdrop voltage is that voltage existing between the main anode and cathode during the conducting period.

There are two things that can affect the normal arc drop of a tube: tube temperature, or the presence of foreign gases in the tube. In general, the higher the temperature of the tube, the lower will be its arc drop. Hence it will tend to carry more current than other cooler tubes in the rectifier. When a tube has high arc-drop voltage because it is leaky, it should be replaced at the earliest opportunity. Tests for leaky tubes have been fully detailed already. If in the event of unbalanced tube currents the maintainer is unable to correct the trouble by giving attention to the above factors, he should call in the manufacturer's field engineering representative.

The degree of current unbalance that is unacceptable will vary, depending on the application and whether or not the rating of the power rectifier equipment utilizes the full ability of the tubes. However, ±10 per cent unbalance between the tubes is usually acceptable, but attention should be given to those cases where it exceeds 10 to 15 per cent at full-load rating of the rectifier equipment.

Operation with Less Than the Normal Tube Complement

Sealed-ignition rectifiers may be kept in service when one or more tubes are disconnected or for other reasons are carrying no current. This advantage is often made use of in maintaining service to some important process or operation until it is convenient to shut down the rectifier and replace a faulty tube.

It is, however, bad practice to operate the rectifier for extended periods of time and under all conditions of load without the full, normal complement of tubes. Without the normal tube complement there will be unbalanced current in both the transformer secondary windings and in the tubes themselves. Although, in general, this does not cause excessive transformer heating, critical results may occur in the remaining tubes which are called upon to carry the whole rectifier load. In most rectifier circuits, when one tube is disconnected one of the remaining tubes may be called upon to carry nearly twice as much peak current as it would otherwise be carrying if all the tubes in the circuit were carrying their share.

If, for instance, it is necessary to operate a rectifier with a six-phase, double-wye transformer with one tube disconnected, the maximum continuous load should be reduced to approximately 60 per cent of rated current. This is a good rule to follow, as a matter of fact, for most sealed-ignitron rectifier circuits. When a tube reaches the end of its life for any reason whatsoever, the only safe step is to replace it just as soon as possible.

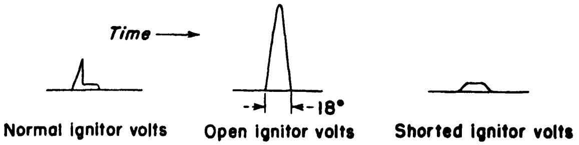
Unplanned Service Interruptions

The maintenance man is always faced with the remote possibility of an unplanned interruption of power. He must be prepared to locate trouble quickly and repair it so that the apparatus may be immediately returned to service. Sealed-ignitron rectifiers, in common with other electrical apparatus, are provided with switchgear and control designed to protect automatically the rectifier equipment and the systems to which it is connected from abnormal operating conditions. It is not unnatural that a feeling of bewilderment should come over the maintenance man when he is suddenly faced with an emergency, such as an unplanned service interruption. However, by recognizing the fact that what has happened is normal, because the control is designed to take the equipment out of service automatically in cases of trouble, he can quickly eliminate the psychological strain of the emergency. The control, by functioning in accordance with its designed purpose, is valuable insurance against serious equipment damage.

The control for sealed-ignitron rectifiers is nearly always designed to offer protection against the abnormal conditions listed in Table XV, in the manner indicated.

When the maintenance man knows what abnormal conditions the equipment is automatically protected against, it is a simple matter for him to inspect the various relays to see which one caused any given interruption.

As an illustration, suppose that a rectifier has disconnected itself from the system because of failure in the motor winding of a water-circulating pump. The maintenance man arriving at the rectifier will find that either the d-c breaker, or both the a-c and d-c breakers, are open, depending on the type and design of the rectifier. When he tries to reclose them and place the unit back in service, he finds he cannot. It follows, then, that some one of the protective relays is indicating an abnormal condition. Hasty examination of the three or four protective relays should show that the water-pressure relay indicates loss of water pressure. There are two possible causes: loss of water from the cooling system, or a failure of the water-circulating pump. Obviously, because the water-circulating pump is very accessible, it should be inspected first and the maintainer may find that the pump is not turning over. The next obvious point to inspect will be the thermal overload protective devices for the motor, which will have tripped the motor-control circuit if the motor is burned out.



Normal ignitor volts   Open ignitor volts   Shorted ignitor volts

FIG. 9-25. Scope traces showing various ignitor voltage wave shapes.

Effect of Reverse Direct-current Power

When it is known that it is possible to have regeneration of power that cannot be reabsorbed by the d-c system, the user usually buys a dynamic braking protective panel with the rectifier. This protective panel consists of a load-absorption resistor, contactor, and voltage-sensitive relay. When conditions of regeneration are present, the d-c voltage of the system increases above the nominal voltage level of the d-c system; and the overvoltage relay automatically closes the contactor and applies the resistor to the system.

The magnitude of the d-c overvoltage caused by regeneration may reach proportions high enough to cause the rectifier to arcback.

Another source of excess d-c voltage can arise from lifting magnets when they are deenergized. Surges as high as 2,000 or 3,000 volts have been measured on 250-volt systems which were caused by lifting magnets. In cases of surges of this sort, it is necessary to connect a nonlinear-type resistor, such as Thyrite, across the d-c system to absorb and prevent the surge.

TABLE XIV.—INSPECTION CHART

Period	What to inspect	What to look for
Program for every 24 hr, or every shift, or otherwise, as determined by local conditions.	Rectifier:	
	a. Water flow	Make sure rectifier has adequate cooling water.
	b. Cooling system	If system is recirculating, check level of water in system. See if water is leaking anywhere.
	c. Tube operation	Note if all tubes are firing and carrying load.
	d. Operating temperature	See if any part of rectifier is too hot. If there are electric heaters on rectifier, check to see if they are operative.
	e. Records	Record any arcbacks or tube replacements in daily log book.
	Transformer:	
	a. Operating temperature	Note thermometer reading.
	b. Liquid level	Note liquid level if transformer is oil or askarel* filled.
	c. Liquid leaks	See if any liquid leaks are noticeable.
	d. Fans	If fans are used, make sure they operate properly.
	e. Diaphragms or gas seals	Make sure any diaphragms or gas seals are tight.
	f. Transformer noise level	Listen to transformer. Any erratic bumping noted may indicate tube misfire.
	Switchgear and control:	
	a. Power circuit breakers	See that breakers are in the operating positions they are supposed to be in, *i.e.*, opened or closed.
	b. Ignition checking relay	See if this relay indicates presence of ignitor misfire.
	c. Heating	See that no part of the switchgear is unreasonably hot.
	d. Meter readings	Observe voltmeters, ammeters, wattmeters, and any other station instruments to see if load conditions are normal. Record them in daily log book. Record notes on any work done or repairs made in daily log book.

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* Noninflammable liquid for transformer cooling.

TABLE XIV.—INSPECTION CHART (*Continued*)

Period	What to inspect	What to look for
Program for every month, or otherwise as determined by local conditions.	General:	
	a. Clean the complete rectifier unit. NOTE: The rectifier should be disconnected from both a-c and d-c power systems for complete safety.	Wipe off dust and dirt from all apparatus and blow or vacuum-clean the dust from switchgear, control relays, ignitor excitation equipment, tubes, tube seals, tube insulator supports, cooling system, surface cooler, auxiliary power transformers, etc. In effect, this means to clean carefully everything that is accessible without major disassembly.
	Rectifier cooling system:	
	a. Water-circulating pump	Inspect for excessive vibration.
	b. Water-flow relay	Test it to be sure its contacts will operate by turning the water supply off and on.
	c. Water-pressure relay	Test it to be sure its contacts will operate by stopping and starting the water pump.
	d. Thermostatic water valve	Test it to be sure it will operate to control water flow by cutting water supply too low for the load being carried at incoming supply valve. This will cause temperature to increase and thermostatic valve should open wide. Then suddenly open supply valve and the thermostatic valve should close suddenly. If it doesn't close completely, inspect for trash in valve seat. Check temperature range between complete open and complete closed position. (Should not exceed 5°C.)
	e. Leaks	Inspect complete cooling system carefully for any water leaks.
	Tubes:	
	a. Load balance	Measure and record the anode current in each tube with clip-on ammeter.

TABLE XIV.—INSPECTION CHART (*Continued*)

Period	What to inspect	What to look for
	b. Color of arc	Note color of arc to see if tube has become leaky.
	c. Mechanical	Note any water leaks or evidence of cracks in glass seals, coating on seals, or deterioration of leads and terminals.
	d. Arcback	If the rectifier has arced back during previous month, test the vacuum of each tube, using spark coil, click, or bubble test.
	e. Tube temperature	Check operating temperature of each tube to see if temperatures are within proper limits.
	f. Excitation tubes	If thyratron tubes are used in excitation circuit, check them for color and emission.
	Excitation equipment:	
	a. Connections	Inspect wiring for loose connections.
	b. Heating	Look for any evidence of overheating.
	c. Operation	Test to see if each ignitor gets proper impulse and also test to see that the firing timing is correct.
	Transformer:	
	a. Relays	See that any transformer protective relays function as they are supposed to.
	b. Gas absorbers	If gas absorbers are used, inspect for damp or caked compound and replace if necessary.
	c. Core and coils	If transformer is dry type, inspect leads, horizontal surfaces, and ventilating ducts, and clean if necessary, with clean, dry air or nitrogen. Eliminate any causes of corrosion.
	d. Temperature alarm	See that alarm functions properly.
	e. On water-cooled transformers	Check temperature of ingoing and outgoing water and also water pressure and flow.
	f. On forced oil-cooled transformers	Inspect pump glands, oil level, cooler screens, and oil screen for defects, leaks, or dirt accumulations.

TABLE XIV—INSPECTION CHART (*Continued*)

Period	What to inspect	What to look for
	g Load ratio control apparatus	Check adjustments and operation of contact making voltmeter, relays, fuses, etc.
Program for every 12 months or otherwise as determined by local conditions	Rectifier:	
	a. Electric heaters	Inspect for burnouts and replace any that have failed. Remove any corrosion.
	b Cooling system	Clean out any accumulations if the system uses direct raw water. The period will depend on local water conditions. Open water connections at the tubes and inspect for evidences of corrosion or deterioration in both piping and water jackets of the tubes.
	c. Dry plate rectifiers	Test each stack to see if any disks have failed.
	Transformer:	
	a. Inside of tank	Look for sludging or water condensation under cover or on top of core and coils. Remove any present after lowering liquid, by washing with oil or askarel from nozzle at high pressure (80 psi)—then remove and filter. NOTE: The period for such inspections may be increased, depending on load and ambient temperatures.
	b Fan lubrication	Lubricate with grease or oil recommended by manufacturers. NOTE: Avoid excess grease.
	c. Tap changer	Operate to make sure mechanical parts are in good condition and surfaces smooth.
	d. Connections	Check all accessible connections including internal terminal boards for tightness.
	e Load ratio control	Filter and clean oil in ratio adjuster and contactor compartments. Clean all inside surfaces. See that contactors make good contact. Amount of load and number of operations determine life

TABLE XIV.—INSPECTION CHART (*Continued*)

Period	What to inspect	What to look for
		Check contact pressure after installing any new contacts needed.
		Inspect arcing ratio adjusters for wear, alignment, and tip pressure.
		Inspect stuffing boxes on rotating shafts and keep them oiltight. Glands may be taken up but avoid excessive tightening, which causes scoring.
		On mercury-type stuffing boxes see that mercury head is at proper level.
		Check limit switches and reversing relay for dirt and corrosion and remove any present. Check proper mechanical operation by operating throughout complete range at least once a year.
		Check brake shoes for wear, commutator of motor for commutation, and rotating parts for free operation and proper alignment.
		Inspect ventilators and free them of any obstruction.
	Air circuit breakers:	
	a. Connections	Inspect all connections for looseness or heating.
	b. Mechanisms	Tighten all loose nuts, bolts, screws, or cotter pins. See that all moving mechanisms operate freely, oiling or greasing where necessary. Replace worn parts. Operate mechanisms several times manually as complete check. Make sure everything is clean and properly aligned.
	c. Contacts	Check condition of arcing contacts, dressing or replacing any that are burned or pitted. Check for correct pressure.
	d. Tripping devices	Test for proper calibration. See that mechanical parts move freely, are clean, and strike a positive blow that will open breaker.

TABLE XIV.—INSPECTION CHART (*Continued*)

Period	What to inspect	What to look for
	e. Cleanliness	Use kerosene or naphtha. Wipe dry with clean cloth. Do not use liquids that may dissolve plastics.
	f. Heating	When breakers are carrying load, check to see if there is any abnormal heating.
	Power circuit breakers:	
	a. Oil	If it is an oil breaker, the oil should be kept to 22,000 volts dielectric strength. It may be necessary to inspect more often than every 12 months, depending on load and frequency of operation.
	b. Mechanical	See that breaker mechanism operates freely by manual method. Clean and lubricate all toggles, buffers, dashpots, etc. Test and adjust breaker stroke to agree with manufacturer's instructions.
	c. Electrical	Operating voltage should be correct. Check closing relay and clean. Replace burned-out indicating lamps. Test operating time. Test tripping arrangement, preferably by actually operating relays electrically. Inspect, clean, and test undervoltage devices, auxiliary switches, and interlocks. See that all bushings and insulating parts, both internal and external, are clean. Give bushings hi-pot test. Inspect for cracks. Remove arc chutes and clean loose arc products from chute. If arc chute is moist, heaters should be installed to keep arc chutes dry.
	d. Oilless breakers	For oilless breakers access to the contacts is easy. For oil breakers the tank must be removed or, if the breakers are too large, the oil must be withdrawn and access obtained through manhole in the tank.

TABLE XIV.—INSPECTION CHART (*Continued*)

Period	What to inspect	What to look for
	e. Contacts	Check contact alignment, see that surfaces make contact with firm, even pressure and are adjusted according to manufacturer's instructions. Dress roughened contacts with a file or sandpaper and replace contacts that are burned beyond repair. When dressing line-pressure contacts, be sure to maintain the intended line contacts.
	f. Relays	Each relay element should be tested for overcurrent, time setting, current, potential, pickup, dropout, etc., at intermediate points. Where power circuit breakers are operated from relays, such relays should be operated electrically to trip the power circuit breakers.
	g. Metal enclosures	Metal-enclosed switchgears should be deenergized and then opened, and all internal parts, especially insulators, wiped clean. These precautions are especially necessary in dusty, salty, or acid atmospheres.
	h. Voltage regulators	Remove cover and clean out dirt or dust. Wash or replace dust filters in cover. Test calibration of regulator and readjust if necessary. Inspect contacts for burning or evidence of heating and dress or replace if necessary. See that all moving parts are free in action.
	i. Indicating lamps	Replace weak or burned-out lamps and test for proper electrical indication.
	j. Control switches, bus bars, and connection bars	Inspect these carefully for damaged parts, which should be repaired or replaced. Any evidence of overheating should be corrected by tightening, replacing, or removing excess load if present.

TABLE XIV.—INSPECTION CHART (*Continued*)

Period	What to inspect	What to look for
	k. Small transformers	Small transformers should be inspected to make sure that they are clean and that all connections and fuses are intact.
	l. Rheostat mechanisms	Clean, lubricate, and adjust them.
	m. Interlocks	Test all interlocks to make sure that they function as intended.
	n. Meters and instruments	All meters and instruments should be examined and tested by a competent meter technician.
	o. Contactors	Clean and inspect for evidence of heating. Replace burned contacts or charred coils. Test for freedom of moving parts. Adjust and test for proper contact pressure. Tighten all connections, inspect and clean, or replace dirty or broken arc chutes and barriers. Replace any damaged flexible shunts.

TABLE XV.

Abnormal conditions	Protection provided by means of	Number of the device if fully automatic
1. D-c short-circuit current and overload.	D-c breaker with instantaneous and time-delay overcurrent trip.	72
2. Arcback.	D-c air circuit breaker reverse and overcurrent trip. A-c power-circuit breaker* inverse time and instantaneous overcurrent trip.	72 and 52
3. Main transformer overtemperature.	Contact-making thermometer, or winding temperature-detector circuit and relay.	49
4. Loss of water flow.	Water-flow relay.	63W
5. Loss of water pressure.	Water-pressure relay.	88W
6. Water overtemperature.	Thermostatic relay.	26W
7. Ignitor misfire and failure of tube to conduct current.	Misfire detection circuit, relay, and alarm or signal light.	46

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* NOTE: When the rectifier is fully automatic, it is usually equipped with an automatic recloser which returns the complete rectifier back to service after an arcback.

TABLE XVI.—TROUBLE CHART

A TABULATION, IN CONDENSED FORM, OF SUGGESTIONS FROM THIS CHAPTER

Trouble	Possible causes	Tests and how to determine the cause and location of the trouble and other suggestions	Remedy
Arcback interruptions	1 Leaky tubes	Color test Click test Bubble test Inspection for cracks High-frequency spark coil High potential test	Replace faulty tube
	2 High mercury-vapor pressure	Overload on one or more tubes because of tube current unbalance Overload on complete rectifier Improper operating temperature (either too high or too low)	Correct the condition producing high tube temperature
	3 Dirt inside tube	Reaches the end of tube life	Replace faulty tube
	4 Excess phase control	Excess load and phase control Discoloration on inside of glass anode seal Trial-and-error tube replacement Magnetic links and surge-crest ammeters	Adjust transformer taps for minimum phase control Replace faulty tube
Failure of tube to conduct properly	Complete failures		
	1 Broken or loose ignitors	Hook-on ammeter	Change ignitor, replace faulty tube, repair transformer or firing circuit NOTE. Operation permissible at approximately 60 per cent of rated rectifier load with one tube out of service
	2 Ignitor burned off	One tube has no arc glow	
	3 Tube filled with air	One tube is perceptibly cooler than the others	
	4 Open transformer winding	Noise in transformer	
	5 Trouble in firing circuit	Misfire relay operation	
	Misfire		
	1 Wet ignitor	Oscillograph test of ignitor volts	Change ignitor or replace faulty tube
	2 High-resistance ignitor	Compare instrument readings and oscillograph tests of firing circuit with similar data showing normal behavior	
	3 Faulty ignitor firing circuit		
	4 Excessive ignitor firing requirements	Make firing requirement test	
	Unbalanced tube currents		
	1 High tube arc-drop voltage	Test anode-to-cathode arc volts by oscillograph	Replace faulty tube or correct condition causing unequal tube temperatures
	2 Unequal tube temperature		
	3 Gassy tube		

TABLE XVI.—TROUBLE CHART (*Continued*)

Trouble	Possible causes	Tests and how to determine the cause and location of the trouble and other suggestions	Remedy
D-c overvoltage or surges.	1. D-c motors such as used for cranes, ore bridges, etc., on d-c system regenerating d-c power. 2. Lifting magnets cause surges.	Recording d-c voltmeters and ammeters on d-c system.	Dynamic braking protective panel, resistor, or Thyrite should be connected across d-c system.
Unplanned service interruption.	1. D-c short-circuit overload.	Main d-c breaker has tripped.	Hunt for location of trouble and correct condition causing it.
	2. Arcback.	Both a-c and d-c breakers have tripped and lockout relay operated.	
	3. Overtemperature in main transformer.	Transformer thermometer reading, or winding temperature detector relay operated.	
	4. Loss of water flow.	Water discharge has stopped and water-flow relay operated.	
	5. Low water pressure.	Water pump stopped or water-pressure relay operated.	
	6. Water overtemperature.	Thermostatic relay operated.	
	7. Ignitor misfire.	Noisy transformer. Misfire relay operated alarm, light, or bell.	

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